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ABSTRACT

This report was prepared as an account of work sponsored by the United States Government. The report documents a Stanford Research Institute study of the potential roles that solar energy technologies could have for meeting U.S. energy needs over the next 45 years. Computer simulations of different energy supply projections were developed by varying the input parameters of energy demands and energy costs. Three of these projections were chosen to be developed and expanded into broader scenarios. First, the implementation measures required to realize these scenarios were delineated. Then, the economic, socioeconomic, sociopolitical and environmental issues associated with different energy futures were identified, and these issues were compared among the three scenarios. Finally, six major societal issues were synthesized from an analysis of the scenarios. These issues and the three scenarios were evaluated from the perspectives of individuals in different perceptual frames of reference. This report includes a glossary of terms and a reference and bibliography section. (Author/MA)

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A Preliminary Assessment

DSE-115/1

Division of Solar Energy
Energy Research & Development Administration
Washington, D.C. 20545

March 1977

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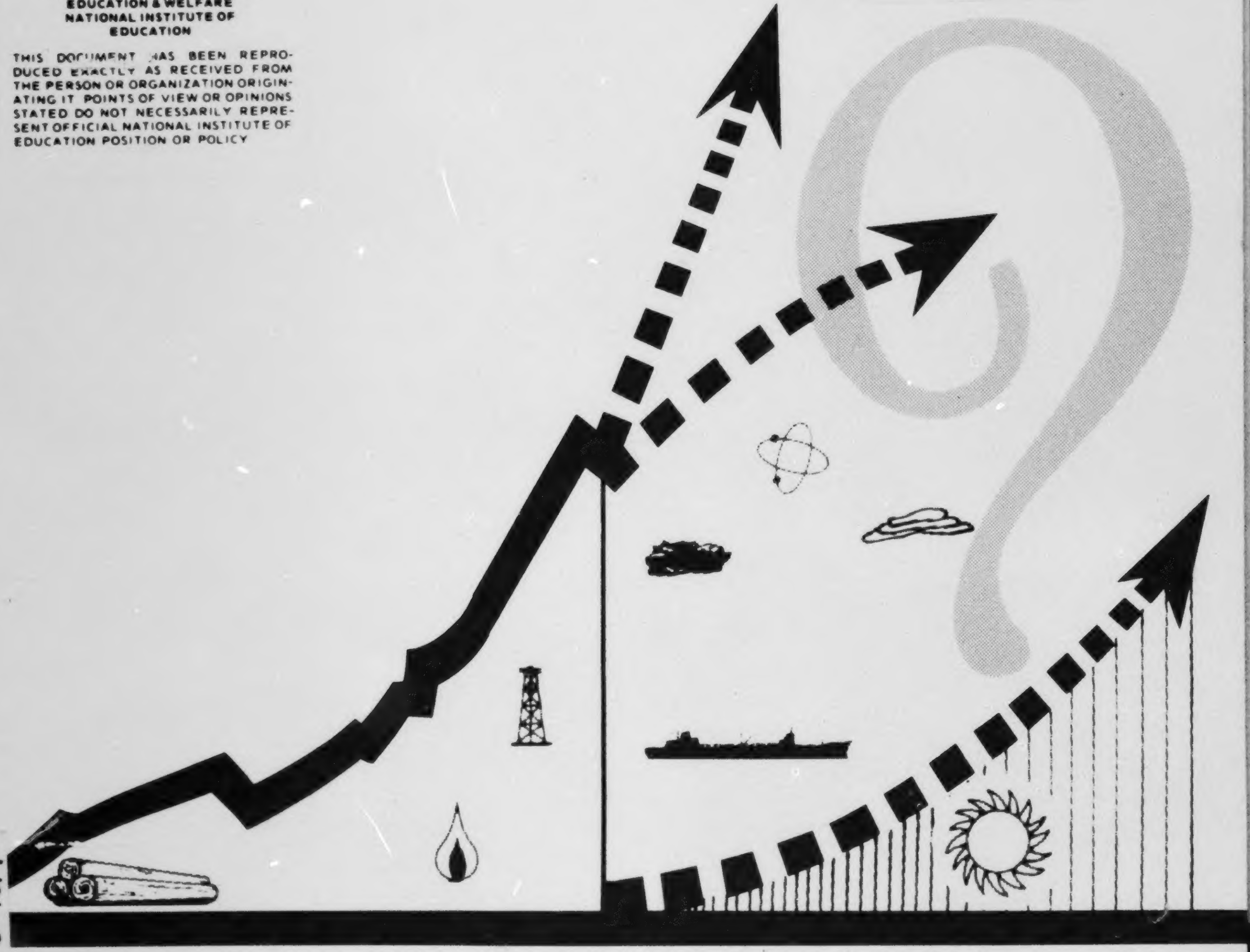

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The report documents a Stanford Research Institute study of the potential roles that solar energy technologies could have for meeting U.S. energy needs over the next 45 years. Computer simulations of different energy supply projections were developed by varying the input parameters of energy demand and energy costs. Three of these projections were chosen to be developed into broader scenarios—that is, richer scripts of the future. First, the implementation measures required to realize these scenarios were delineated. Then, the economic, socioeconomic, sociopolitical and environmental issues associated with different energy futures were identified, and these issues were compared among the three scenarios. Finally, six major societal issues were synthesized from an analysis of the scenarios. These issues and the three scenarios were evaluated from the perspectives of individuals in different perceptual frames-of-reference.

EXECUTIVE SUMMARY

INTRODUCTION

The continuing depletion of domestic fossil fuels may be a signal of one of the most significant long-term issues facing the United States as it enters its third century. The impacts of decisions made today concerning our remaining natural resources will persist for generations, beyond the lifetime of today's children. Solar energy will be an important part of these decisions.

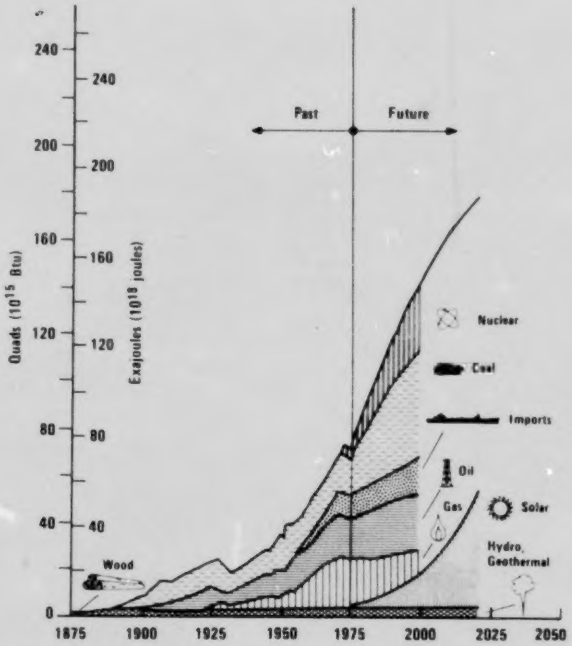
Assuming that global energy resources could sustain 1000 years of use at the current energy consumption rates, those energy resources would be consumed in about 100 years if energy use continued to grow at a rate of 3.5% per year. (From 1950 to 1973, the annual growth rate of energy consumption was about 3.5%). If, however, we assume that there are vast new fossil and nuclear resources yet to be found—enough for 10,000 years of use at today's rate—and that, through technology we can economically tap these resources, they would last 170 years at the 3.5% growth rate. There is considerable disagreement regarding the size of the world's nuclear and fossil resources, and there is considerable disagreement regarding the technical, economic, and social feasibility of many energy technologies. There are few, however, who argue that current growth rates can continue indefinitely.

In this study, we have learned that the United States must plan to deal with the major technical, economic, and social transitions that will occur as we shift from one energy basis to another. Further, we have learned that the nation can begin turning now to renewable resources such as solar energy.

NATIONAL SOLAR ENERGY PROGRAM

The United States Energy Research and Development Administration (ERDA) is responsible for research concerning the nation's energy future. ERDA has contracted with the Stanford Research Institute (SRI) for this study of the social and economic implications of the United States' solar energy program.

As part of its responsibility, ERDA must assess the impacts that new technologies might have upon society. One of its reports, ERDA Report No. 49—*National Solar Energy Research, Development and Demonstration Program,* describes the program for the utilization of solar energy. This program projects a dramatic growth in the solar energy technologies. In this projection the nation's total energy supply grows from today's 73 quads* to 180 quads by the year 2020, and solar energy would meet 25% of this total, i.e. 45 quads. The ERDA-49 plan would require the creation of a comprehensive solar energy industry in 45 years that will supply as much energy as today's petroleum and natural gas industries combined. In addition, the ERDA-49 plan projects a nuclear industry that will supply about 30 quads of electricity per year as compared to 2.2 quads last year. Fossil fuels would supply 100 quads. The ERDA-49 plan is depicted in Figure 1.



NOTE: The ERDA 49 program has projections through the year 2020 for the total scenario (180 Quads), for the solar component (45 Quads), and through the year 2000 for the other energy supply sources.

Figure 1 Energy Projections of the ERDA-49 Program

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*See Note on page vi.

SOLAR TECHNOLOGIES

Solar energy is a unique form of energy because it appears in so many different forms. Figure 2 depicts some of the paths through which it can pass to produce useful products. These products are fuel, power, electricity, and heat. Solar energy can be initially captured by two general types of collectors: natural and engineered. Solar energy can be naturally collected through geophysical processes such as warming the ocean surface and driving the winds and by the photosynthetic action of plants. Solar energy can also be captured by engineered solar collectors explicitly designed for this purpose. To understand how these different forms of solar energy are ultimately converted into useful energy, we will trace through some of the processes that can be used for these conversions.

When solar energy is captured in a plant by photosynthesis, chemical energy is stored. This trapped energy can be viewed as a fuel and directly used simply by burning the plant in a combustion process. In this case the plant itself is the fuel. For many applications, however, it is convenient to convert this plant into a more familiar form of fuel. To accomplish this, the plant itself is sent through a chemical conversion process such as pyrolysis, digestion, or fermentation to produce either a gaseous or a liquid fuel that is similar to conventional gas and oil.

Sunlight warms the upper layers of the ocean. At the same time, deeper in the ocean the water is cooler. This temperature difference between the surface of the ocean and the lower levels of the ocean can be used to drive a heat engine. This process is commonly called the ocean

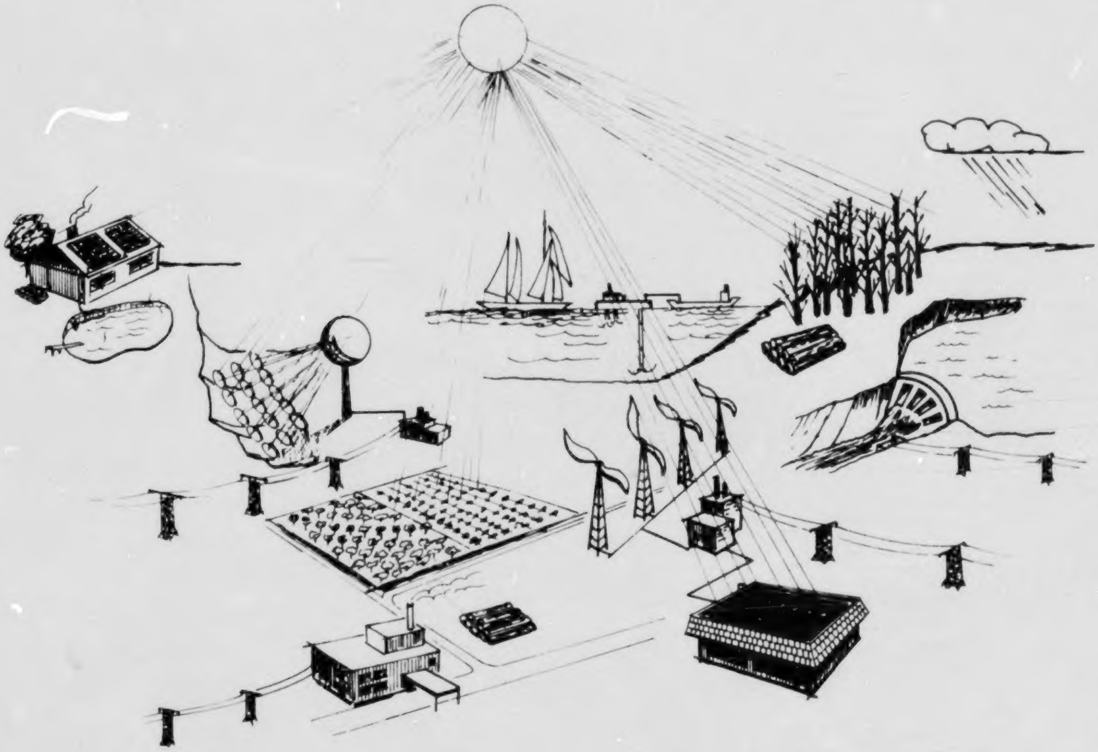

Figure 2 **Solar Energy Conversion Processes**

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* A commonly used gross measure of energy supply is quadrillions of Btu (Btu x 10^{15}), also called a quad. One quad is approximately equivalent to:

180 million barrels of petroleum
42 million tons of bituminous coal
0.98 trillion cubic feet of natural gas
293 billion kilowatt hours of electricity

Note: In this study, we account for solar energy in terms of "primary fossil fuel equivalent" (ffe)—fuels saved from the resource for which solar substitutes. This accounting concept for solar energy is used throughout the report.

thermal energy conversion system or OTEC. This OTEC process converts the thermal energy captured in the ocean into mechanical power that can be subsequently converted into electricity. The third form of natural collector is the winds. Differential solar heating of the earth gives rise to the winds that can be converted into mechanical power by a wind turbine. This mechanical power can then be converted into electricity or simply used to pump water.

There are two general classes of engineered collectors. The first of these is photovoltaic cells. Photovoltaic cells directly convert incident sunlight into electricity. The second form of engineered collector is a thermal collector designed to convert the incident solar energy into heat. This heat can subsequently be used directly for industrial process heat, agricultural drying, or building space conditioning. Alternatively, this collected solar heat can be used to drive a heat engine to produce mechanical power. This power can be subsequently used to produce electricity, pump water, or for other uses. Although other forms of solar energy are possible (such as direct photolysis of water), the above are the routes that are generally considered to be practical and that have been considered in this study.

METHOD OF APPROACH

To analyze the social and environmental implications of solar technologies it is necessary to know how much solar energy will be used, which solar technologies will produce it, where it will be used, how much it will cost, and the other energy supplies displaced by solar. To accomplish this, it is necessary to examine solar energy technologies within the context of total energy supply and demand of society.

This study is a type of technology assessment; that is, a study "... that systematically examines the effects on society that may occur when a technology is introduced, extended, or delayed..." The general logic of a technology assessment is (1) to delineate the likely future of the technology, (2) to assess the impacts of the technology, and (3) to identify the key issues and decision options that emerge. Figure 3 depicts the approach used in this study.

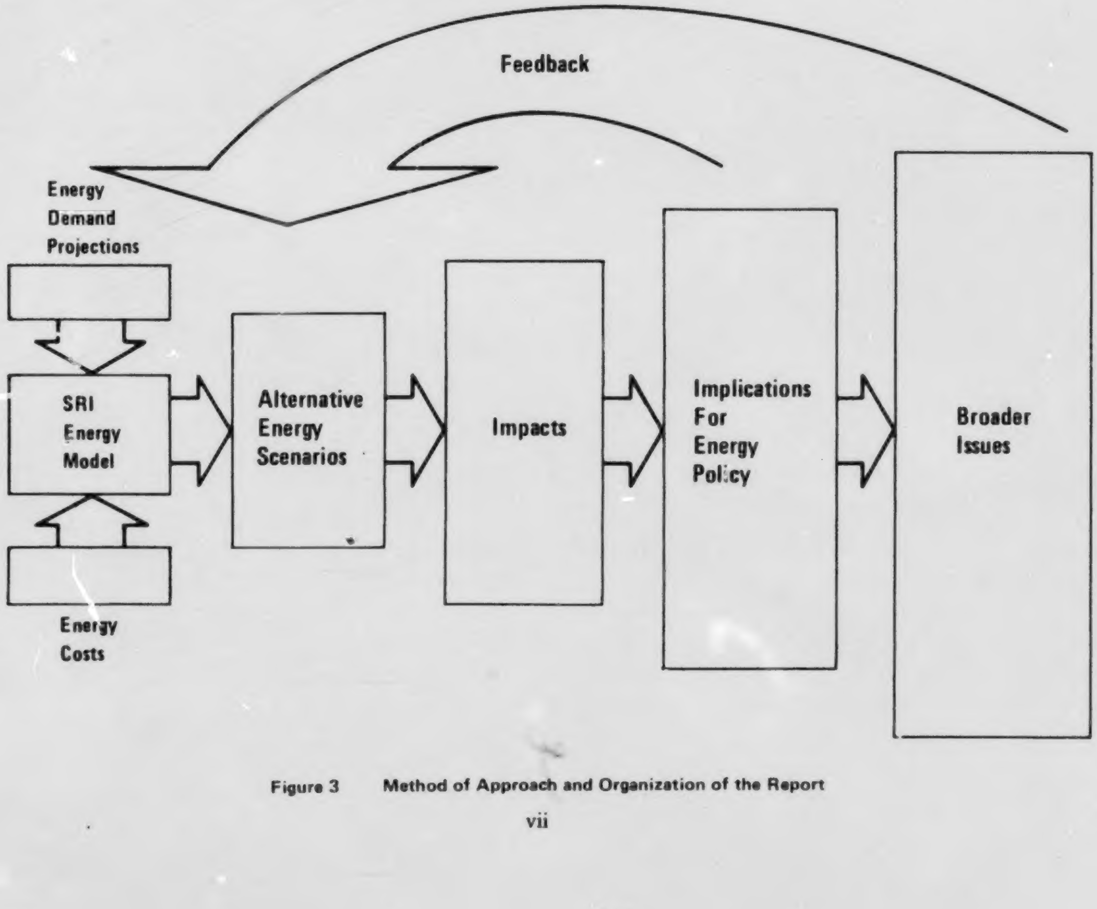

Feedback
Energy Demand Projections
SRI Energy Model
Energy Costs
Alternative Energy Scenarios
Impacts
Implications For Energy Policy
Broader Issues

Figure 3 Method of Approach and Organization of the Report

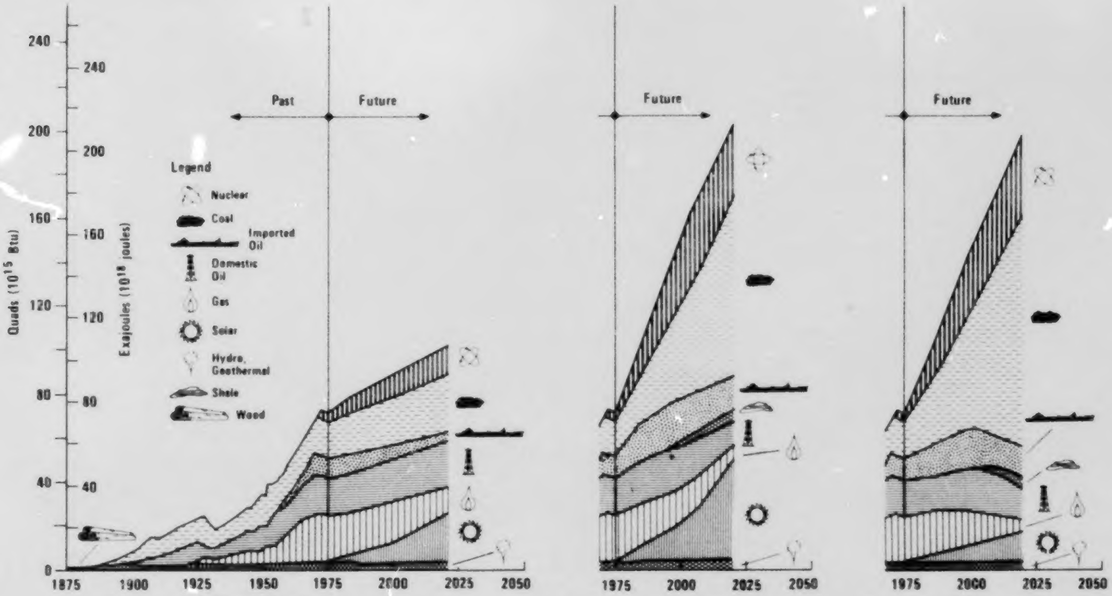
Examining the energy sector in detail consists of analyzing the demand for energy of different forms (e.g., liquid fuels, electricity), the cost of energy resources (e.g., coal, oil) and energy processes (e.g., conversion, storage, and transmission), and the resulting market shares of these resources and processes. Because these variables are interdependent, it is desirable to be able to simulate or model these interrelationships and to observe their behavior with time. Such simulations, called scenarios, can depict future energy demand/supply patterns. Computer-based models are necessary for these simulations because such models permit the simultaneous consideration of thousands of variables. Our simulations come from the SRI energy model that uses estimates of quantities of resources in the ground, costs of extraction, transportation, and conversion to usable energy to calculate the cost of each future energy source at its point of use. The model then chooses the most economical means of meeting energy needs.

TABLE 1

ENERGY SCENARIOS
TOTAL ENERGY SUPPLY IN THE YEAR 2020 (In quads)

	1975	*Reference*	*Solar Emphasis*	*Low Demand*
Biomass	1	1	11	4
Solar Heating	0	10	22	16
Solar Electricity	0	0	11	0
Total Solar	1	11	44	20
Hydro and Geothermal	3	4	4	4
Total Renewable	4	15	48	24
Nuclear	2	37	34	15
Domestic Oil and Shale	19	18	17	21
Oil and Gas Imports	13	16	14	3
Domestic Gas and LPG	21	7	8	13
Coal	15	105	83	26
Total Nonrenewable	69	183	156	78
GRAND TOTAL	73	198	204	102

The simulations include the following energy pricing concepts: *Resource cost* usually is not a direct function of time; it is a function of the amount of resource mined or pumped. As cheap coal is mined or oil and gas are pumped, only more expensive coal, oil, or gas remains. For any given resource, resource prices generally increase as richer deposits are exhausted. *Process costs* change with time as technical progress and mass production act to lower costs, and tighter environmental controls and higher costs of labor and capital act to increase costs. *Energy price and energy demand interact:* higher demand usually results in higher energy prices, and higher prices lead to lower demand.



Low Demand Scenario **Solar Emphasis Scenario** **Reference Scenario**

Figure 4 Three Energy Futures

Resource costs include economic rent or "scarcity rent"—the difference between the real cost of producing a product, including normal profits, and the price of the product. Economic rent is the extra cost of a product caused by the knowledge that the product is limited in supply and will be more expensive in the future. Economic rent performs the socially useful purpose of charging higher prices to today's consumers in order to reduce today's consumption and leave more for the next generation of consumers.

The SRI energy model was used to help generate the *reference, solar emphasis,* and *low demand* scenarios detailed in this study. These scenarios are not predictions; rather, they are three internally consistent examples of numerous potential future energy supply mixes. They are intended to present a range of energy futures. Each person may consider one or more of the scenarios highly improbable. Each scenario is, however, a consistent framework to study the consequences of alternatives. The energy supplies for each scenario are presented in Table 1 and Figure 4. These scenarios were compared in terms of economic, environmental, and social impacts on various interest groups. Implementation steps required to make each scenario possible were identified. From this comparison it was possible to derive implications of the scenarios.

It is important to note that this report is not based on simple straight-line projections of future oil and gas costs. Although oil and gas costs have risen rapidly over the past few years, it is unlikely that such rates can continue for very long. For example, at a steady 10% annual increase, oil would cost more than $150 a barrel by the year 2000. Because such estimates are clearly above competitive energy costs, using such constant rates of increase would be unrealistic.

The economic evaluations made in this study are based on the assumption that equilibrium prices for energy will generally prevail over the 45-year time frame of the study. Because it is impossible to predict future governmental policies and because it is possible to make estimates of future prices of fuels based purely on economics, the latter approach provides a useful baseline from which to evaluate alternative policies. In this regard the most important assumption for this study is that natural gas prices will be deregulated—a reasonable assumption because natural gas is limited in supply and will be replaced in the time frame of this study by more expensive substitutes such as synthetic gas from coal.

SIMULATION RESULTS FOR SOLAR ENERGY

In terms of initial installation costs, solar energy is nearly always more expensive than nonsolar energy. However, because sunlight itself is free and other fuels are not, a solar system might be economically advantageous if we consider the total energy system costs over the system lifetime.

The prospects for solar energy depend on its relative advantages compared with potential competitors. The comparison must be performed for each potential solar market including residential and commercial heating, industrial heating, natural gas from biomass, and electricity. All these potential uses of solar energy are conditional on ending a variety of governmental policies that reduce the price of natural gas and electricity below "free market prices." These policies include natural gas price regulation, low-interest loans for federal electricity, and tax exemptions of state and municipal electric systems.

Residential and Commercial Heating

Solar energy appears to be highly competitive for water heating. Although the initial cost of a solar water heater is high (between $1000 and $1500 for an average home)*, it becomes moderately less expensive than gas heat and much less expensive than electric heat when evaluated on the basis of total cost over the lifetime of the system.

The market for solar residential/commercial space heating is more difficult to penetrate, based upon our baseline cost estimates of $4000 for a residential solar heating system, because the greatest demand is in midwestern and northeastern states at a time of year when cloudy conditions often prevail. On the other hand, when alternative fuels are expensive, such as areas where natural gas is not available, solar energy is likely to dominate the space heating market for new construction as soon as the year 2000.

Industrial Heating

The largest industrial use of energy is for relatively low-temperature hot water and steam. Providing industrial process steam with solar energy has the same advantages as providing domestic hot water in that it is a year-around use. However, solar industrial steam and hot water are not likely to be competitive with direct burning of coal to produce steam. It appears that, except in special situations, solar would only be used where coal use is not feasible or is prohibited.

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* All costs are constant 1975 dollars.

Biomass

Biomass is a limited resource compared with essentially limitless sunlight. About 1 quad of forest and agricultural residues and municipal waste are now used to produce energy and up to 10 quads are available. However, collection costs are too high for most of this resource to be used to produce energy unless competing fuels rise in price or raw biomass resource costs fall 50% below current forecasts. Biomass based on plantation growing is less likely to be competitive, and marine biomass appears even more expensive than terrestrial biomass.

Solar Electricity

Solar electricity has potential for meeting the demand for "intermediate" load electricity. (Intermediate load is that electricity above base load that is used from about 7:00 AM to 9:00 PM.) Intermediate load electricity is more expensive than base load electricity when provided with conventional or nuclear technology because costly generating plants are idle half the day. On the other hand, solar electric plants can provide intermediate load electricity at cheaper costs than solar-generated base load electricity because the load occurs when the sun is shining and less storage capacity and collector area are required. Based upon our baseline cost assumption, however, (that solar intermediate power plants will cost $1600/kW(e)) synthetic high-Btu gas from coal appears to be less expensive and is solar's main competitor.

It appears that solar electric processes will not be competitive for base load electricity with present and projected costs for coal and nuclear power.

HOW TO CLOSE THE COST GAP

We have now reviewed the most important potential markets for solar energy. In two of these, water heating and certain space heating markets, solar energy is likely to be cost competitive with little further federal assistance if direct and indirect federal subsidies to competing forms of energy—electricity and gas—are removed. In such a situation and assuming that the total U.S. energy supply increases from today's 73 quads to about 200 quads in the year 2020 (the reference scenario), solar energy could provide about 11 quads of this total.

There is, however, a significant cost gap between solar and competing nonsolar energy sources in most residential/commercial heating, industrial heating, biomass, intermediate electricity, and base load electricity. There are three direct ways to reduce the cost gap: technical progress, direct solar subsidies, and increased costs of alternative energy sources. In addition, there are two indirect means: lower interest rates and life styles more amenable to using solar energy. We discuss each of these briefly in the next paragraphs.

It is possible that some new invention will appear or some new technology will work, thereby reducing future solar costs below current forecasts. However, such breakthroughs are far from automatic. If solar cannot be made cost competitive through technical progress and mass production, direct subsidy is an alternative. With sufficient subsidy it would be possible to reach any desired level of solar energy supply, but any subsidy of any energy supply makes energy cheaper and to that extent it discourages conservation. As a rough indicator of the dollars involved we estimate the following annual subsidy costs beginning about 1990 (when the solar electric technologies are likely to be commercially available), (see Chapter 2 for complete discussion of this analysis): about $10-20 billion to reach 30 quads solar, $20-30 billion to reach 45 quads solar, and about $30-60 billion to reach 70 quads solar by 2020. (The amount of solar energy per dollar of subsidy decreases as the solar contribution increases because it becomes progressively more difficult to reach higher levels of solar energy use.) Portions of this subsidy, however, are returned to various facets of society in a variety of ways (e.g., lower energy costs, lowered consumption of nonrenewable resources, lowered environmental pollution costs). We elaborate at length on these points in the report.

The strategy of encouraging solar use through taxing or otherwise increasing nonsolar costs can have certain benefits. If the energy problem is viewed as using too much irreplaceable fossil and nuclear resources, then a reasonable policy alternative is to increase the price of these resources. A policy of increasing the price of nuclear and fossil fuel has at least two major effects: it discourages overall energy consumption by making energy more costly, and it encourages the use of renewable energy resources such as solar.

Because solar is so capital intensive, its economic feasibility is largely dependent on interest rates. For this reason a reduction in interest rates would reduce the relative costs of solar energy more than that of other energy supply systems.

It has been assumed that solar systems must be designed to be just as reliable and responsive as traditional energy sources. This adds large storage costs for solar systems. A modest life style change to adapt human activities to solar availability would reduce this extra cost. Each consumer's life style, with its unique value system, influences his or her market choices. Because solar is purchased directly by the consumer, it could be purchased for life style rather than economic reasons. This distinction between economically based and life style decisions can be essential to solar feasibility.

OVERALL SIMULATION RESULTS

Based on a number of computer simulations of alternative energy projections we have synthesized three energy scenarios for detailed analysis.

Reference Scenario

The reference scenario simulates a total gross energy consumption close to that of ERDA-49; the energy supply shares are determined by economic forces based on baseline cost assumptions. Solar energy contributions to this scenario are modest, even by 2020, because most nonsolar processes are less expensive than solar processes. Solar energy captures only about 1.5% of the market in 2000 and approximately 6% of the market in 2020.

Results of this scenario are:

- Western coal production increases dramatically, from about 130 million tons per year at present to nearly 4 billion tons per year by 2020. Coal production in the East and Midwest also increases rapidly.

- Nuclear power increases from the equivalent of 34 one-thousand-megawatt nuclear power plants in 1975, to over 600 one-thousand-megawatt plants in 2020.

- Natural gas production increases slightly from current levels of 19 quads per year, but begins declining after 1985, reaching a level of 6 quads per year in 2020. The reason for the declining production of natural gas is the depletion of this resource from domestic sources.

- Shale oil production enters the market after 1990, reaching 5 quads annual output by 2020.

- Domestic crude production increases until 1985; thereafter it declines to approximately current production levels (15 quads), because of the depletion (rising cost) of the resource.

- The largest synthetic fuels production is high-Btu coal gasification and coal liquefaction.

Solar Emphasis Scenario

The solar emphasis case uses solar costs 50-70% lower than in the reference case. All other assumptions are identical. The cost reductions are those necessary to produce a solar market share approximating that in ERDA-49. By 2020 the results of this scenario are:

- Solar energy increases to 44 quads. The increase from 11 quads of solar heating in the reference case was: 11 quads of solar intermediate electricity; 11 quads of biomass; 7 quads of solar residential and commercial space heating; and 4 quads of solar industrial/agricultural heat.

- Solar substitutes almost entirely for coal. Western coal output declines by 14 quads (slightly less than one billion tons per year) compared to the reference case. Eastern coal declines by 8 quads, over 400 million tons per year.

- Nuclear declines from 37 to 34 quads.

- All other energy supplies are essentially unchanged.

Low Demand Scenario

In the low demand case, costs of nonsolar energy sources were raised to meet potential objections that the reference scenario nonsolar energy prices are unrealistically low and do not include environmental and social costs associated with nuclear and fossil fuel energy production and use. This scenario treats nonsolar energy prices as reflecting some of the costs of environmental degradation, social dislocation, and depleting resources for future generations. Because these social costs are not adequately considered in private markets, nonsolar energy sources are taxed in rough correspondence to their social costs. Taxing fossil and nuclear energy rather than subsidizing solar energy avoids the difficulties of implementing any subsidy. (Subsidizing any energy source, including solar energy, discourages conservation of energy to some degree by making energy prices lower than they would otherwise be.)

To develop the low-demand case, a substantial conservation commitment by the United States is assumed—a commitment that is implemented by forcing energy prices to double by 1985 and increase another 50% (or triple) by 2000, and remain level after 2000. This scenario assumes economic growth of 2% per year after 2000.

Results of this scenario are:

- Solar energy (including biomass) totals 20 quads by 2020.
- Fossil fuels are saved for the future, with about 35% less cumulative production between 1975 and 2020 when compared with the reference scenario.
- By the year 2020, western coal production is reduced from over 3 billion tons per year in the reference case to less than one billion tons per year.
- Eastern high-sulfur coal production is reduced by more than 50%.
- Nuclear energy in 2020 is reduced to about the number of plants now under construction or being planned.

ENVIRONMENTAL IMPLICATIONS OF THE SCENARIOS

To achieve the reference case scenario, society must exert enormous efforts, entailing substantial conflict over the resolution of environmental issues. In 2020, the reference case has more than 600 nuclear power plants that, if sited to minimize the cost of delivered electricity to the consumer, would be located near the largest population centers. Thus, the issue of nuclear safety is an important one in the reference case.

Another result of the reference case is the extraordinary development of regions of the American West for energy resources. Not only are almost 4 billion tons of coal mined in the West annually in 2020 (compared to 650 million annual tons today in the entire nation), but coal conversion plants abound. The reference case has 200 coal gasification plants in the Northern Great Plains (Each of these plants is sized to deliver 250 million standard cubic feet of gas per day, enough to heat about one million residences daily). The same area has 150 plants producing 50,000 barrels per day of synthetic crude oil from coal in 2020. (The output of one of these coal liquefaction plants in energy value is about equal to that of one gasification plant). The reference case also has 50 plants producing oil from oil shale in 2020 (each with 50,000 barrels per day output). These plants are located in the Rocky Mountain region of the United States.

Such a massive development of western energy resources, as well as energy conversion on-site, may strain one's credibility, but it is the result of a decision making process based on economic considerations. This intensity of energy development raises serious issues—significant social impacts in the region of resource development, the lack of water and the need to import it (presumably through interbasin transfers), the maintenance of air quality standards, protection of wilderness areas, preservation of the integrity of the land, etc.

Nuclear power and western energy development are the two critical environmental issues of the reference case. To what extent would the solar emphasis case avoid these problems? The answer is that it reduces the impacts only in limited measure. The solar emphasis case has 580 nuclear power plants (versus 630 in the reference case) in 2020. The solar emphasis case has 130 gasification plants in the Great Plains in 2020. This is 70 fewer than in the reference case. And there are 70 oil shale plants in the solar emphasis case, 10 more than in the reference case in 2020.

The low demand case is a vehicle for reducing environmental impacts, if society wishes to choose this route. In 2020 in the West there would be 3 gasification plants, 20 coal liquefaction plants and 20 oil shale plants. The low demand case would have 255 nuclear power plants in 2020. If nuclear power is not acceptable, then there would be supply flexibility to select other resources (particularly eastern coal) to provide electricity. Although the low demand case does not avoid all environmental problems, it appears to be the fundamental direction for society for those who wish to avoid the environmental impacts of the higher demand cases.

ECONOMIC/INSTITUTIONAL IMPLICATIONS OF THE SCENARIOS

The reference case and the solar emphasis case were dominated by environmental considerations. In surveying economic impacts, we call particular attention to the economic impacts of the low demand case. There is now, and there will be for some time, uncertainty about the degree to which low growth in energy demand is compatible with traditional growth in the economy. However, there are substantial opportunities for energy conservation in the United States without lifestyle changes and even greater opportunities with changes in the way we live. Although justifiable fears exist that the immediate impact of higher energy prices could be unemployment, attaining high employment and low energy growth over the long term appears to be feasible. The effects of government economic policies on employment and economic activity will be much greater than the effects of higher energy prices. Measures to compensate the poor and guard against the regressive nature of an energy tax are necessary. Three clear-cut problems remain: industries producing products of high energy content will lose markets; energy industries will achieve greatly reduced growth rates and may be expected to decline substantially in profitability; and the general level of prices will increase with some danger of further inflation. A very important determinant of the acceptability of the low demand case is the degree to which citizens voluntarily choose to alter their lifestyles and live more frugally versus the degree to which coercion is needed to implement lower energy growth rates.

The special economic problem of the reference case is that of high levels of oil imports and this problem is much reduced in the low demand case. The economic assumptions behind the reference case lead to a growth in the nation's dependency on oil imports until after the turn of the century. Even for the solar emphasis case, the problem of oil imports continues to plague the nation.

A wide range of options exist to implement the solar emphasis case, ranging from very intensive solar RD&D to the redesign of utility rate structures to the elimination of subsidies of competing fossil fuels to subsidies for solar energy. Few of these options have as yet been carefully explored, but many of them appear to offer important benefits. Raising the price of fossil fuels (through deregulation, taxes, or removal of subsidies) is a critical implementation measure for any of the scenarios, if substantial solar energy market penetration is to be achieved. The subsidy of solar energy discourages conservation and raises difficult questions about how such a subsidy could be implemented equitably. As solar energy becomes competitive with fossil fuels, the owners of the scarce fossil fuel resources and energy producers lose the extra benefits that derive from expectations of higher prices in the future resulting from increasing scarcity.

STAKEHOLDER RESPONSES TO THE SCENARIOS

To gain an understanding of the distribution of costs and benefits of each scenario to society, it is necessary to analyze reactions of different "stakeholder groups" to the scenarios. Each stakeholder group is comprised of individuals who generally share a common point of view regarding specific decisions because they stand to gain or lose as a result of the decision. Of course, many persons will find themselves part of more than one stakeholder group; stakeholder groups often show great internal diversity regarding their response to a given action; furthermore, membership in and views of stakeholder groups will undoubtedly change significantly over time. This approach, however, has become a useful one with which to assess the broad implications of alternative policies.

The implementation measures will be discussed from the perspective of four different stakeholder groups: energy producers, citizens of energy producing states, environmental interests, consumer interests. Other stakeholder groups could be identified, but these are sufficient to illustrate several of the major issues of the scenarios.

Nuclear Implementation Measures

Local opposition to any specific nuclear power plant is likely. Energy producers as a whole are likely to support legislation ending the legal basis for judicial interference in such decisions. With existing regulatory and judicial procedures the nuclear power levels in the reference and solar emphasis scenarios cannot be achieved. To the extent that measures to prevent nuclear siting delays erode a legal process essential to the more general interests of environmental and public interest groups, these groups may be expected to oppose the measures vigorously.

The selection of sites for long-term storage of high level radioactive wastes will undoubtedly set off controversies of major proportion. Reaction to this issue as well as the issue of the security of nuclear material from theft is not easily addressed in terms of the stakeholder responses, as differing perceptions of the magnitude of the problem cut across all stakeholder groups.

Fossil Implementation Measures

The attainment of socially acceptable reclamation standards for strip mined land has the potential of benefiting most of the stakeholder groups. Environmental and conservation groups benefit from the protection of the landscape afforded by the measures. Although energy producers are subject to higher costs of extracting coal, these costs represent only a very small fraction of the price of delivered energy. Furthermore, national reclamation standards reduce uncertainty facing producers.

Solar Implementation Measures

Reduction of the gap between solar and nonsolar costs is the essential implementation measure for the solar emphasis scenario. This reduction in the relative price differences between solar energy and competing fossil fuels can be achieved through one or more of at least three general mechanisms: (1) research and development and mass production that result in solar costs below those in the reference scenario, (2) solar energy subsidies, and (3) taxes on fossil and nuclear energy.

All three of the mechanisms for achieving the solar emphasis case result in a loss of economic rent to the owners of fossil and (indirectly) nuclear energy resources. In addition, the fossil energy producers lose markets to solar energy. The suppliers of solar energy systems and support industries are unambiguous beneficiaries of the solar emphasis case. A successful R&D program on solar energy reduces energy costs to the consumer. The cost to the consumer of a tax on nonsolar energy versus a subsidy to solar energy depends on how much of the tax is returned to the taxpayer as tax credits or in some other form. Of the three implementation mechanisms, the solar subsidy should be the least desirable from the point of view of the environmental and conservation interests, because a subsidy reduces energy prices and this encourages growth in the consumption of energy.

In any case, the controversy surrounding the solar implementation measures will need to be viewed in comparison to that caused by the fossil and nuclear implementation measures.

Conservation Implementation Measures

It is not difficult to note stakeholders affected by the low demand scenario: owners of energy resources, whose profits are reduced; energy producers, who lose because of reduced long-term growth prospects; owners of and workers in high energy-consuming industries, who pay much higher prices for energy and whose products becomes less competitive; and consumers who will probably pay higher prices in spite of tax refunds. In contrast, environmental and conservation groups will see substantial reductions in environmental degradation, and those concerned with rising oil imports will see imports reduced.

Implementation Summary

Review of these few implementation measures out of a much longer list reveals a pattern that seems inherent to the reference case and solar emphasis cases; this can best be summarized by the word "conflict." Consideration of the implementation measures reveals that economic forces alone are not adequate to bring about the reference or solar emphasis scenario. Social decisions, many of which are likely to be of a divisive nature, must be made to reach high levels of energy supply.

The low demand case represents a major change in the social fabric. The uncertainty in knowing the directions that these changes might take makes the forecasting of stakeholder responses even more difficult. Considering only the reponse of an individual whose immediate self-interest is challenged by a change in the status quo is likely to be an inadequate characterization of the longer run response to the low demand case. Understanding how people will react to fundamental changes in society requires an inquiry into their ideas and perceptions of reality, and when there are so many different "realities" the problem is compounded.

REGIONAL CONSIDERATIONS

All of the energy scenarios imply a fundamental change in the relative wealth of energy-producing and energy-consuming regions. This wealth transfer will take place in two ways: higher energy prices in energy-consuming regions and movement of industry, along with jobs, population, and prosperity away from high energy cost regions.

The introduction of solar energy could exacerbate this problem because, without special regional subsidies, solar energy for some applications is more costly in the North than in the South. The brunt of this higher-energy-cost/job-loss problem will be borne by the Northeast.

In addition to the immediate social problems of development, there is the long run problem of depletion of energy resources in some energy supply regions. Energy supply states could adopt a wide variety of policies for energy development and conservation, and the choice of these policies has a potential for deeply divisive conflict within states and among states.

Within a new producer state, the majority of the citizens are likely to see potential economic benefits from energy development including high wages, more jobs and large capital gains for owners of existing homes, land, and other assets. Opponents of the energy development would include individuals greatly concerned about environmental problems and changing the character of rural areas.

From the regional considerations these conclusions emerge:

- High energy prices and slower energy development are very much in the interests of energy-producing areas. This could be achieved through state tax, land use, public land, and related policies.
- Such policies will be opposed by energy-consuming states.
- A critical conflict in future years will be the issue of states' rights regarding the establishment of energy policies.

INTERRELATIONSHIPS WITH OTHER MAJOR SOCIETAL ISSUES

Because energy use is so intensive and pervasive in industrialized society, energy issues cannot be probed seriously without uncovering the web of national and global issues to which the nation's energy choices are crucial. The most significant broad sociopolitical questions to which these impacts relate center around the following issues.

National and Global Responsibilities

The propriety in terms of world responsibility of the disproportionate amount of world resources used by the United States has been questioned. This imbalance is summarized by the oft-quoted statistic that the United States with 6% of the world's population uses over 30% of the energy consumed. There is growing agitation for a "fairness revolution"–reduced resource consumption by the rich nations and extending a helping hand to the developing nations that seek to better their situation.

Tradeoffs Determining the Socially Desirable Level of Economic Activity

The basic issue is the balance between benefits (e.g., material standard of living) and costs (e.g., resource depletion and environmental impacts) of high economic growth. This includes the relationship between economic growth and resource use, particularly energy.

Needs for and Costs of Governmental Regulation

As advanced, technology-oriented societies grow more complex, the apparent need for governmental regulation mounts. Yet the price of increased regulation is high–in terms of interferences with the functioning of the market economy, bureaucratic inefficiencies, and threats to civil rights and liberties. Because the increasing complexity of the society is intimately related to its use of energy, as energy use rises the call for more regulation tends to rise with it.

Centralization vs. Decentralization

Technically there are few compelling reasons to make decentralization of solar energy an important issue. Economies of scale in solar technology go both ways. Decentralization of *control* is an issue, however, both at the individual level and at the system level. Individually, concerns are expressed that modern industrialized society engenders a sense of alienation and impotence and, hence, a desire for ownership and/or control of the technology that affects one's life. At the system level, distribution of control tends to increase the adaptability and resilience of the system. The symbolic power of the decentralization issue should not be underestimated. Solar energy is democratic; it falls on the rich and the poor, the weak and the powerful. There is reason to believe that the issue of decentralization of energy sources may turn out to be surprisingly vigorous and persistent.

Predominant Societal Goals

There is evidence that emergent values are challenging the traditional national goals of material progress and dissemination of the "American Way." The tension between old and new is evident and present in every energy-related issue. Such issues as the amount of energy the society should plan for in the future, and how determined the society should be in developing solar technology in preference to less benign technologies, gain their imperativeness in part because they are so intimately related to this fundamental tension.

Rationality Governing Decision Making

Basic sociopolitical decisions involve noneconomic factors, and often, basic philosophical issues. Economic rationality has both its strengths and its weaknesses as applied to such decisions. Applying economic rationality where it doesn't fit can lead to unwise policy choices. This basic tension is a key to many contemporary issues surrounding energy and resources.

REPRESENTATIVE VIEWS OF REALITY

Underlying the attitudes of various interest groups toward solar energy, conservation, the breeder reactor, etc., can be discerned divergent pictures of the "real" energy situation. In the public debates over energy issues, adversaries sometimes seem to be talking about different realities. Once identified, there may be ways of dealing with these discordant perceptions of reality—ways that permit communication and ease conflict.

Although these perceptions are multifaceted and each implies a different ideology, for brevity they can be compared by contrasting their views of the energy problem:

Perception A - The energy problem is essentially a problem of developing supplies to meet the expanding energy needs of a dynamic society; simultaneously, conservation measures need to be adopted to reduce wasted energy.

Perception B - Continued energy growth incurs increasingly intolerable social, environmental, and ecological costs; energy demands need to be cut back drastically through voluntary choice of a more frugal lifestyle made equitable by supporting legislation.

Perception C - The energy problem is but one manifestation of a far more fundamental crisis involving nothing less than the future course and/or survival of industrialized society.

All three of these perceptions represent views found among decision makers, analysts, and citizens. In a democratic society, all have to be honored in some sense. No one of these three views can be disproven by "facts" drawn from another. Whichever view society comes to accept, that view will tend to become more "real." We introduce the three perceptions, A, B, and C, to help understand some of the conflict surrounding energy-related issues and, hopefully, as a tool to help improve communication and reduce conflict.

ISSUES BEHIND THE ISSUES

In the process of examining the social and environmental implications of alternative ways the United States might pursue its energy future, issues have emerged that are broad and fundamental. These can be summarized in the following two conclusions:

- In the light of the interrelationship between energy and the overall shape of society, it is a serious and potentially very hazardous error to allow major energy decisions to be based only on technological and economic arguments.
- The most critical of current energy-related questions is: What are the full social benefits, costs, and risks of a national shift toward reduced energy growth and maximum reliance on renewable energy sources?

It is imperative that there be full and open communication with the public about the complete range of social implications of these issues, and ample opportunities for public dialogue and participation.

OVERALL CONCLUSIONS

Energy policy for the future will continue to be made amid great uncertainty—particularly uncertainty about future attitudes, values, and behaviors. The range of and choice among energy options will be significantly affected by U.S. attitudes toward energy frugality, economic growth, employment, environmental quality, business and industry, equitable economic opportunity, regional environmental sacrifice to meet national needs, rights of other nations to the Earth's resources—and by attitudes of the rest of the world toward U.S. energy-consumption patterns.

The most significant fact about energy in the United States of 2020 is not the quantities supplied and used in that year, but where the trends point after that. The key uncertainty affecting the long-term energy future is public attitudes toward nuclear dependence, in addition to the uncertainty surrounding the technological development of nuclear fusion.

If society decides not to move toward dependence on nuclear energy, then there is only one other viable direction. After fossil fuels have been exhausted and except for the appearance of some totally new technology of which at present we have no idea, the only alternative is a solar-dominated energy economy with moderate energy demands.

Solar energy is not a cure-all for our energy problem; but combined with a larger strategy that includes energy conservation, cascading, and some sacrifice of convenience, solar energy does offer the option of a society based upon a renewable source of energy.

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PREFACE

This report documents an eight-month, $275,000 study conducted by Stanford Research Institute (SRI) under a contract with the Energy Research and Development Agency (ERDA). The plan for the study was developed during the fall of 1975 when it became evident that the development and commercialization of solar energy technologies could have far reaching implications for the United States and that these implications should be analyzed.

In March 1976, ERDA contracted with SRI and with Energy and Environmental Analysis (EEA) to undertake research into these issues. EEA would focus upon individual solar technologies and their site-specific impacts, and SRI would analyze the implications of the solar energy technologies from a broader societal perspective. To cover the spectrum of issues arising from the interplay of technical and social forces, the SRI study team of staff and consultants was assembled from a range of disciplines in engineering and the social and policy sciences, and with experience in solar energy, energy economics, environmental analysis, economic policy, futures research, and social policy analysis.

SRI finished the first phase of its research with an interim report, "A preliminary Social and Environmental Assessment of the ERDA Solar Energy Program, 1975-2020" in June 1976. ERDA assembled a panel of outside consultants for a weekend workshop and review of the interim report, and as a result, significant changes in direction and emphasis were agreed upon. These included more attention to an analysis of critical aspects of economic and social implications of the scenarios and particular emphasis on a scenario with future energy demand levels in the year 2020 only about one and one-half today's levels (somewhat more than half the ERDA-49 demand level for that year). In early August copies of the draft final report were delivered to ERDA and also to a number of consultants for review.

In November 1976, an extension of the contract was negotiated and SRI began the final three months of work. Among other things, the organization and approach of the report were changed to aim for a broader readership than was originally planned. We hope we have succeeded in this goal.

In any study, the resource and time constraints establish limits in terms of both scope and detail. We have not analyzed in any depth the time period beyond the year 2020, although some important issues come into focus during the next century. We do identify these issues. Similarly, the study has not analyzed alternative energy futures on a global basis. Rather, we have focused on energy futures for the United States. Yet global implications of U.S. energy policies can, in turn, impact those same policies. We do identify some of these issues. Finally, energy policy is of interest to extraordinarily diverse interest groups—each with positions on one energy policy or another. In this study our role has been as analysts, not as advocates. Our function has been research into the implications of policy options. The report is, in this sense, a research agenda of unresolved issues whose resolution is critical to the economic and social future of the nation. Perhaps its primary contribution will be to provide a framework for discourse about our national energy future and in illuminating the "issues behind the issues."

Several ERDA staff have been particularly important to the study as project monitors, including James Benson and Fred Kommanoff.

Consultants and advisers contributed essential advice throughout the project. These included R. N. L. Andrews, Roy Rappaport, Donald Michael, Kan Chen, and John Willett of the University of Michigan; Sam Bleicher of the University of Toledo; Herman Daly of Louisiana State University; Charles Hauer, private consultant; Byron Kennard, National Council for the Public Assessment of Technology; Larry Moss, private consultant; Michael Nolan, Midwest Research Institute; Ronald Stewart, State University of New York; and Gordon Enk, Institute on Man and Science.

SRI staff who made significant contributions to the study include: Bill Chan, Bob Fullen, Pat Henry, Floyd Lewis, Tom Mandel, Dale Nesbitt, Lou Perica, Bill Rousseau, Robert Steele, Tom Thomas, and Leo Weisbecker. Space does not allow for acknowledgements here to the many others who supported us during the project. To each of you—Many Thanks.

1 INTRODUCTION

A. PURPOSE OF THE STUDY

> Solar energy—clean, free, safe and eternal—the answer to our energy problems—the basis for future lifestyles more in harmony with our natural environment.

> Solar energy—expensive, undependable, and useful only in warm, sunny climates—of negligible value in meeting U.S. energy needs—a romantic dream of those who want to return to a more primitive existence.

The public attitudes to solar energy are so divergent that it's almost as if those at opposite points of view were seeing different worlds. The purpose of this study has been to look at what's behind the often heated debate about energy—to analyze in detail the role solar energy could play in the U.S. energy future.

Energy is, however, a means to an end in society, not an end in itself. It is the ability of energy to do useful work that is valued, not energy itself; and work, too, is but a means to still higher ends. Work in this broad sense of the word is the means by which people meet their individual and group needs—the ways in which individual and societal goals are accomplished.

Thus, it is social policy, not energy policy or economic policy, that is the broader concern of this study. Both energy and economics are important elements, as are the natural laws that serve as boundaries or constraints upon energy, economic, and social processes, but the central interest is to illuminate social policy choices.

This comparison of social choices requires that the various benefits of energy options be arrayed against their many costs. Furthermore, these costs and benefits must be assessed from the perspectives of all of the many interest groups that are affected. As we shall see, the energy options for the future that are assessed in this report are so far reaching in their implications that they would affect every citizen, including those yet to be born, for decades and even centuries into the future. For these reasons this report has been prepared for a wide audience. It is the public who will be called upon to face and make these choices.

B. THE BIG PICTURE

The sun is the major source of energy for the earth. Solar energy sets the atmosphere and oceans in motion, creating the winds and ocean currents; it drives the hydrologic cycle, the primary determinant of climate; it makes possible photosynthesis—the conversion of sunlight into stored chemical energy. The sun was responsible in remote geologic time for the formation of fossil fuels. These processes constitute the conversion

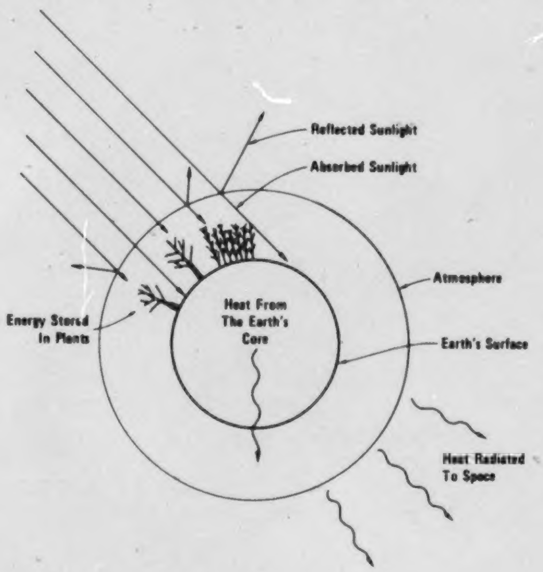
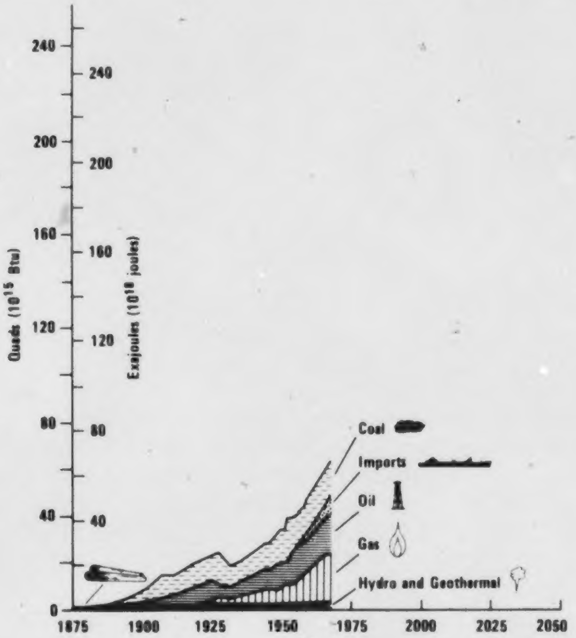


Figure 1-1 The Sun as the Major Source of Energy

of the sun's energy into countless different forms before it is ultimately degraded into low-temperature heat and radiated back into space. This global system is in equilibrium with the incoming energy in the form of ultraviolet, visible, and infrared radiation balanced by the outgoing heat radiation (See Figure 1-1).

For centuries, humankind augmented the daily influx of solar energy by drawing upon stocks of stored solar energy–first from plants for food, from animals for food and work, and from trees for shelter and heat; then from wind and falling water for power. The practical marriage of coal and the steam engine in the mid-18th century, however, constituted a technological leap in man's ability to use energy in concentrated forms. The next leap began in the mid-19th century when oil was discovered in Pennsylvania. Transportation was revolutionized by the new liquid fuels and the success of the automobile, and industrialization took on a new dimension.

In the United States the demand for energy from stored sources rose rapidly (see Figure 1-2), as technological advances piled one upon the other. Abundant, low-cost energy was used to fuel the Western economy, and the growth of energy-intensive industry has manifested itself in an increase in the per capita consumption of energy (Figure 1-3). The federal government has projected a continuing rise in energy comsumption for the U.S. through the year 2020 (see Figure 1-4) despite the recent drop in overall energy consumption during the oil embargo and the economic slowdown that followed.



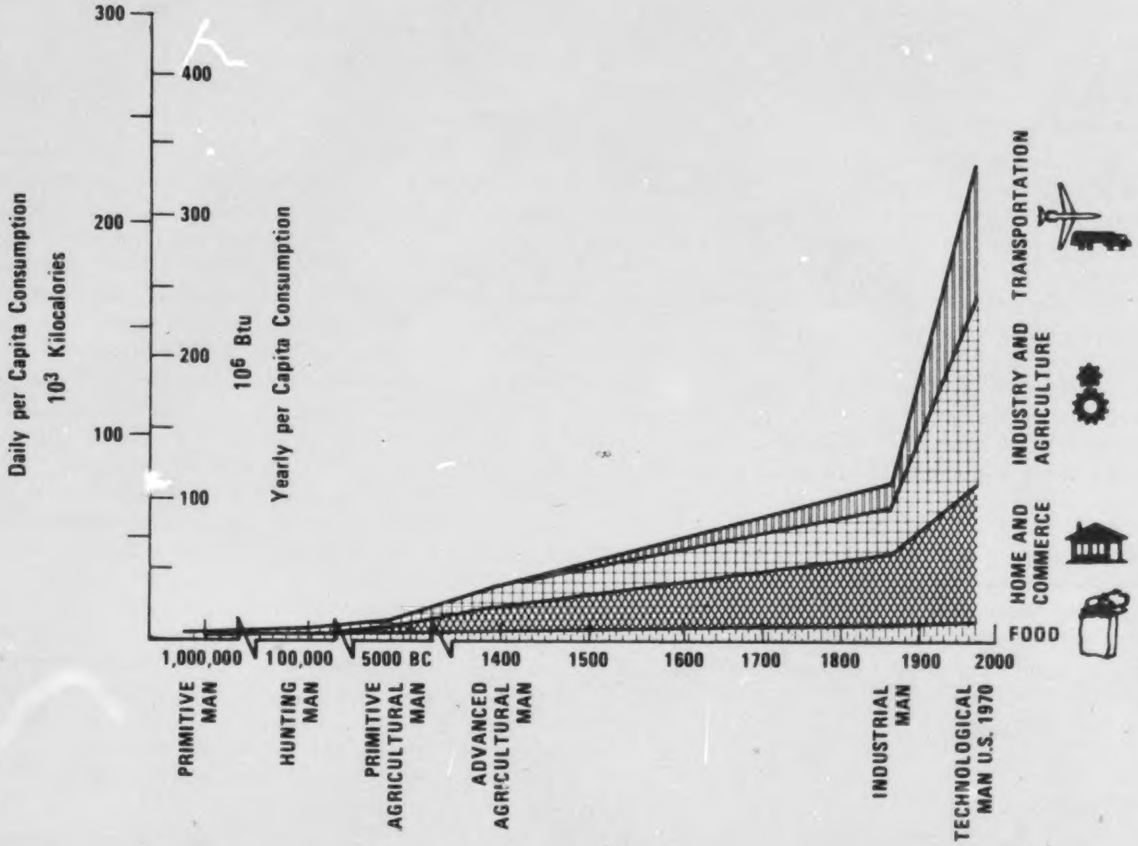
NOTE: The energy supplied by any particular source is shown as the distance between adjacent curves.

Figure 1-2 U.S. Energy Consumption through 1970

There has been, however, a rise in the impacts associated with the use of these forms of stored energy. These impacts manifest themselves as, for example, air pollution from automobiles, and water pollution from industrial wastes and agricultural runoff. Both the United States and the world are now affected by a growing number of resources that are becoming scarce and more expensive (See Mining and Minerals Policy 1975). A number of authorities attribute the strains in the earth's ecosystems directly to humankind's increasing per capita impact upon the environment (Brown, 1970; Committee for Environmental Protection, 1970; Study of Critical Environmental Problems, 1970). In addition, the population of the world has increased to 4 billion people (see Figure 1-5), and it is likely to rise to 6- 7 billion during the next 25 years (Figure 1-6). Many observers see this factor alone as cause for alarm (Spilhaus, 1970; Erhlich, 1970; Brown, 1970; Borgstrom, 1970). And, as many of these sources note, the per capita impact upon the global environment acts as a multiplier to the population level (See also IIASA Reports). Thus, if the population doubles and per capita impact triples, the total impact upon the environment goes up by a factor of 6.

The western world, and the United States in particular, has set a pattern of energy consumption that the underdeveloped peoples of the world could naturally view as goals for themselves. The seriousness of this situation can be deduced from studying world energy projections. We refer to an earlier pre-embargo study (see Figure 1-7), in which world energy consumption was projected to triple from 215 quadrillion Btu (quads) to more than 700 quads by the year 2000 (SRI). Even this large an increase in world energy use, however, would increase global per capita energy a small amount compared to the increase projected for the United States during the same period (see Figure 1-8). In other words, the current gap in per capita energy use between the United States and the rest of the world, rather than closing, would grow even larger.

Finally, there remains considerable uncertainty among resource analysts about the size of the world's fossil resources. A recent paper (Roseman 1973), however, points out that these uncertainties are overshadowed by the fact that energy consumption is not constant but is increasing year after year (See also



"Daily consumption of energy per capita was calculated by the author for six stages in human development (and with an accuracy that decreases with antiquity). Primitive man (East Africa about 1,000,000 years ago) without the use of fire had only the energy of the food he ate. Hunting man (Europe about 100,000 years ago) had more food and also burned wood for heat and cooking. Primitive agricultural man (Fertile Cresent in 5000 B.C.) was growing crops and had gained animal energy. Advanced agricultural man (northwestern Europe in A.D. 1400) had some coal for heating, some water power and wind power and animal transport. Industrial man (in England in 1875) had the steam engine. In 1970, technological man (in the United States) consumed 230,000 kilocalories per day, much of it in the form of electricity. Food is divided into plant foods and animal foods (or foods fed to animals)."

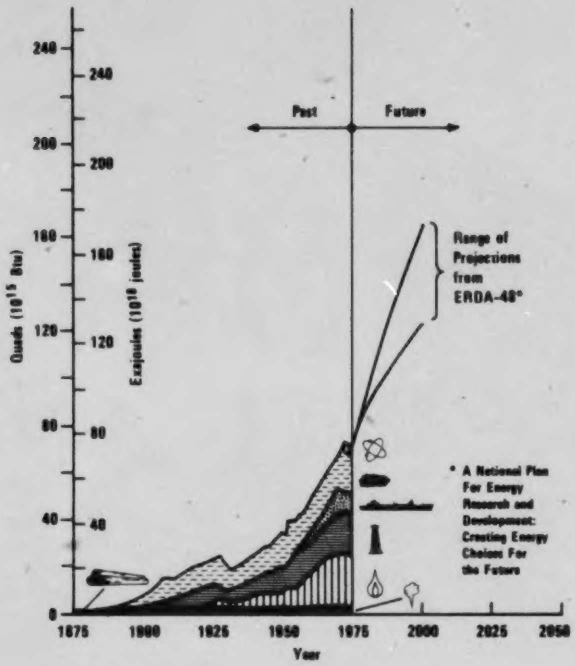
(Reference: Earl Cook, "The Flow of Energy in an Industrial Society," Scientific American, September 1971.)

Figure 1-3 Past Per Capita Energy Consumption

Olds, 1976). For example, if one assumes that the earth's fossil fuels will last for 1000 years at today's global consumption rate of about 215 quads per year, then this same resource base would be consumed in 104 years at a 3.5% growth rate. If one assumes instead that rising energy prices and new technologies will allow us to find and exploit new resources and that these resources are 10 times greater–that is, they would last for 10,000 years at today's consumption rates–then these resources would be gone in 170 years. The growth rate in Figure 1-7 is closer to 4% so the lifetimes of the resources would be even less.

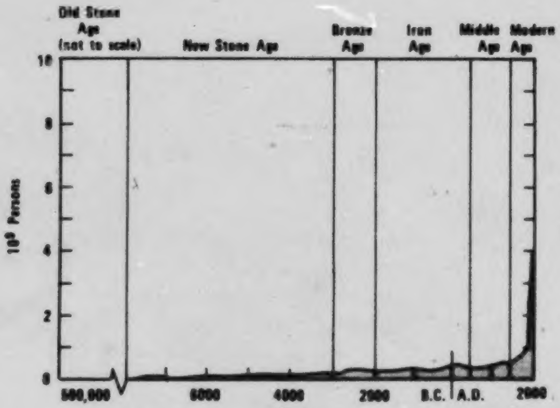
A recent article in *Science* magazine noted this consequence of exponential growth and concluded "Federal energy planners should have attended more carefully to their reading of some of the vast popular and scientific literature addressing the energy crisis... It is exteremely difficult to escape the conclusion that the nation must do something about leveling its currently increasing use of energy very soon." (Christiansen and Clark 1976).

It is within this context, then, that national policy–including energy policy–must be analyzed, and it is within this context that the potential for solar energy is being reexamined.



* A National Plan For Energy Research and Development: Creating Energy Choices For the Future

Figure 1-4 Projections for United States Energy Consumption through the year 2000



If Old Stone Age were in scale, its base line would extend about 18 feet to the left. (After "Population Bulletin," Vol. 18, No. 1.) [Adapted from Ehrlich, 1970]

Figure 1-5 Past World Population Level

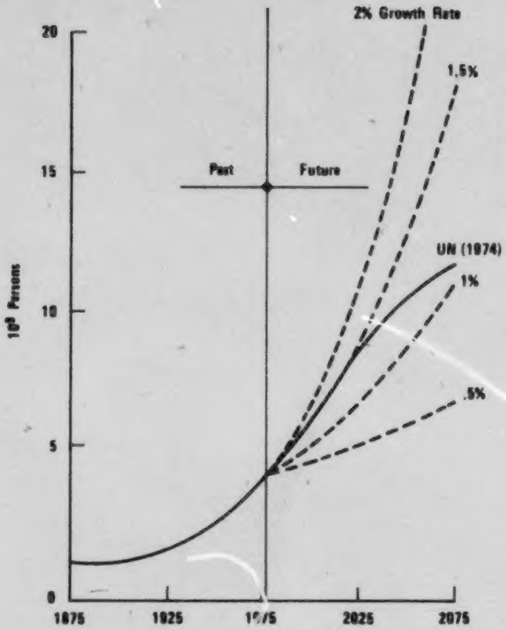


Figure 1-6 Projections for World Population

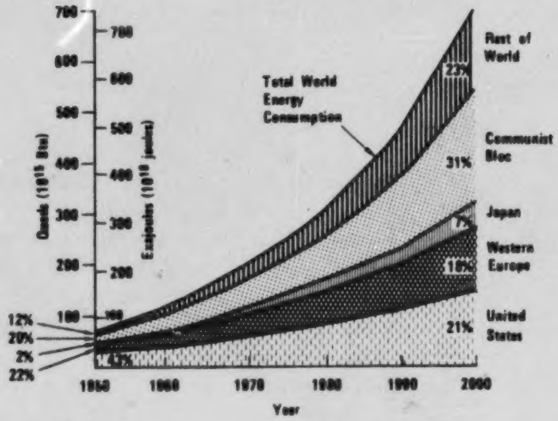


Figure 1-7 World Energy Consumption by Region, 1950–2000

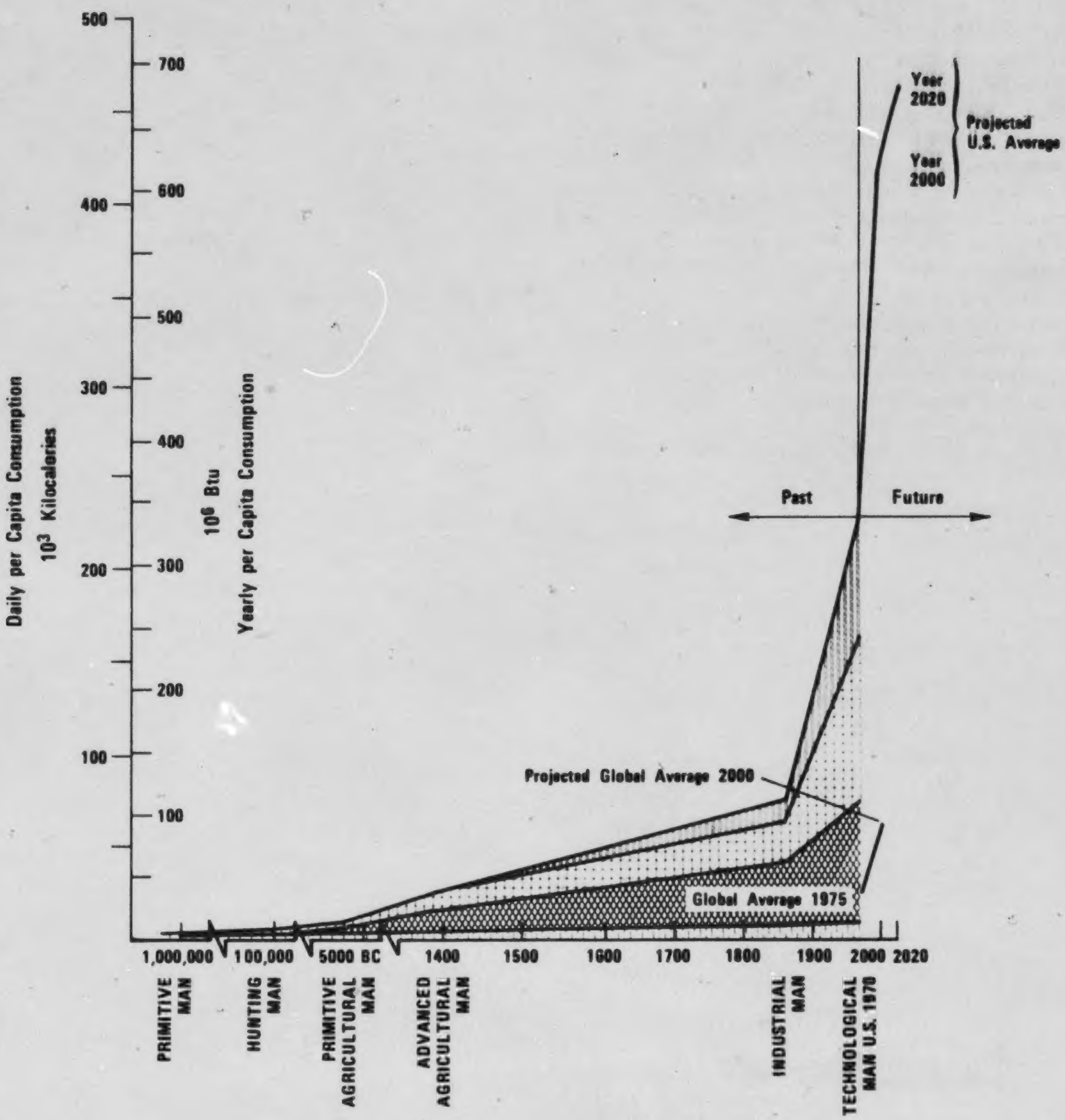
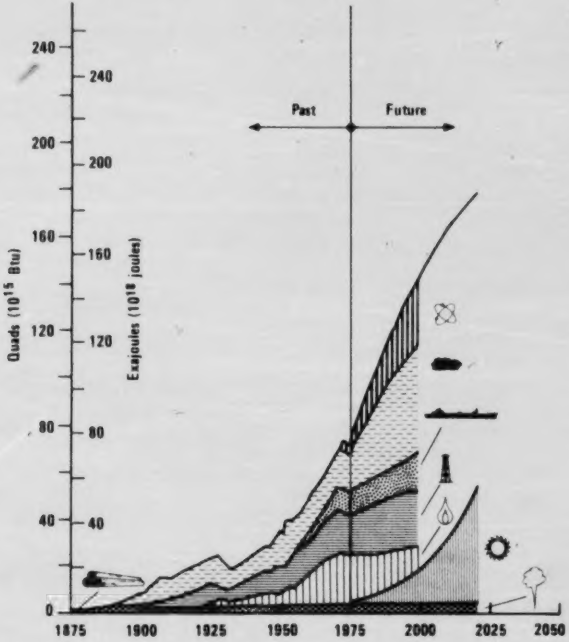


Figure 1-8 Future Per Capita Energy Consumption

C. THE NATIONAL SOLAR ENERGY PROGRAM

The Energy Research and Development Administration (ERDA), created in 1974 by the Congress, has prepared a comprehensive plan for energy research, development, and demonstration. (ERDA-48, ERDA 76-1). ERDA's proposed goals for solar energy are contained in the report, ERDA-49, *National Solar Energy Research, Development and Demonstration Program.* This program projects that 45 quadrillion Btu (45 quads) could be supplied from solar energy by the year 2020. By comparison, the United States used about 73 quads of energy total in 1975, of which more than 75% was derived from petroleum and natural gas. Thus, the ERDA-49 plan would require the creation of a comprehensive solar energy industry in 45 years that will supply as much energy as today's petroleum and natural gas industries combined. In addition, the ERDA-49 plan projects 100 quads of energy from fossil fuels and a nuclear industry which will supply about 30 quads of electricity per year as compared to 2.2 quads last year. The ERDA-49 plan is depicted in Figure 1-9. The solar energy component of this program is outlined in Table 1.



NOTE: The ERDA 49 program has projections through the year 2020 for the total scenario (180 Quads), for the solar component (45 Quads), and through the year 2000 for the other energy supply sources.

Figure 1-9 Energy Projections of the ERDA–49 Program

The creation of a new solar energy industry this large represents in and of itself a major shift in the economic and political infra-structure of the society. Because new solar industries will be required, new employment patterns will result; legal questions concerning sunrights must be resolved; major changes in building codes will be necessary; and the gas and electric utility systems will be affected.

The ERDA-49 program also requires that more than 600 1000-megawatt nuclear reactors be in operation by the year 2020. Thus, problems associated with the nuclear fuel cycle must be solved—problems include the siting of reactors, the long-term storage of high-level radioactive wastes, theft of nuclear materials, sabotage and terrorism, reactor safety, and long-term "storage" of decommissioned reactors.

The ERDA-49 program also requires the mining and processing of about 100 billion tons of coal by the year 2020, more than half of which will be from surface strip mines. By way of comparison, total coal production in 1976 was about 650 million tons. This program will require a major shift in population to the coal states of Wyoming and Montana. Water will need to be piped in from other river basins or from the Gulf of Mexico.

When these impacts and the many others we shall discuss in this report are summed up, serious questions must be raised. What steps will be necessary to implement this program, and how can we, as a society, anticipate the results? How will we manage the problems of environmental degradation? What decisions must be made regarding scarce resources and who will make them? What are the rights of future generations and who will plan and budget for these rights? How will this program affect foreign policy options and the opportunities and risks for economic trade? From a different perspective, what choice do the solar technologies offer when compared with nuclear and fossil fuel alternatives? What are the implications of scenarios that assume higher or lower total energy use than tht assumed in ERDA-49?

In this report these questions are raised, some more completely than others, but the intent is to examine the broad range of issues so that the major consequences of the nation's energy policy alternatives can be assessed.

D. THE METHOD OF APPROACH AND ORGANIZATION OF THE REPORT

The basic approach chosen for this study is that used in a class of studies referred to as technology assessment—a study "...which systematically examines the effects on society that may occur when a technology is introduced, extended, or delayed..." (Coates 1974). The general logic of a technology assessment is (1) to

TABLE 1-1

ESTIMATES OF THE ENERGY AND FUELS TO BE SUPPLIED IN THE UNITED STATES BY SOLAR ENERGY*

(From ERDA-49)

	1985	2000	2020
Direct Thermal Applications (in units of Q=quads=10^{15}Btu/year)			
Heating and Cooling	0.15	2.0	15
Agricultural applications	0.03	0.6	3
Industrial applications (Process heat)	0.02	0.4	2
Total	0.2	3	20
Fuels from Biomass	0.5	3	10
Solar Electric Capacity (in units of thousands of megawatts, GW(e))**			
Solar Thermal	0.05	20	70
Photovoltaic	0.1	30	80
Wind	1.0	20	60
Ocean Thermal	0.1	10	40
Total Electric Capability	1.3	80	250
Equivalent Fuel Energy***	0.07	5	15
Overall Energy Equivalent in Quads	~ 1	~ 10	~ 45
Total Projected U.S. Energy Demand	100	150	180

*These categories and numbers are not identical to those used in the ERDA-48 analyses for 1985 and 2000. They are, essentially, the same within the accuracy of such estimates.

**These numbers represent estimated equivalent rated capacities of conventional plants which are operating at a load factor of 0.6 (5200 hours per year) for 1985, and 0.7 subsequently. They are provided for comparability purposes.

***Assumes a conventional electrical generation efficiency of 32%.

delineate alternative futures of the technology, (2) to assess the impacts of the technology, and (3) to identify the policy options and key issues that emerge. These steps can be repeated to incorporate what was learned the first time in a reexamination of the technologies and their impacts. This cyclic or iterative approach was necessary for this study (see Figure 1-10) because we are not dealing with a simple cause-effect relationship. The society and its energy technologies can be best understood when they are viewed as dynamic and interactive. Our woodburning 19th century was not just impacted by the exploitation of fossil fuels—it was transformed into the industrialized 20th century. Similarly, the nature of society in the 21st century will be shaped significantly by the energy technologies that are chosen to replace natural gas and petroleum.

At each of these three steps in our approach it was necessary to resolve the methodological question. First, how could we delineate alternative futures for solar technologies—how could we combine the superabundant quantitative information on Btus, water heaters, dollars, kilowatts, tons, coal mines and oil wells with the potential of the solar technologies? The solution was to turn to a computer simulation of the U.S. energy system. In this way we could analyze the possible future roles for solar technologies as compared to and in the context of the future of nuclear and fossil fuel technologies. The results of this step are reported in Chapter 2.

The next step was to assess the impacts of the energy projections of Chapter 2—how could we combine the quantitative analysis of Chapter 2 with the often intangible and unquantified information on the impacts? The approach we used was to expand the energy projections of Chapter 2 into richer scripts for the future—scenarios with plans for government actions and social and political choices to be made—until each scenario became realistic and felt as though it could be "lived in." In this way each scenario became an

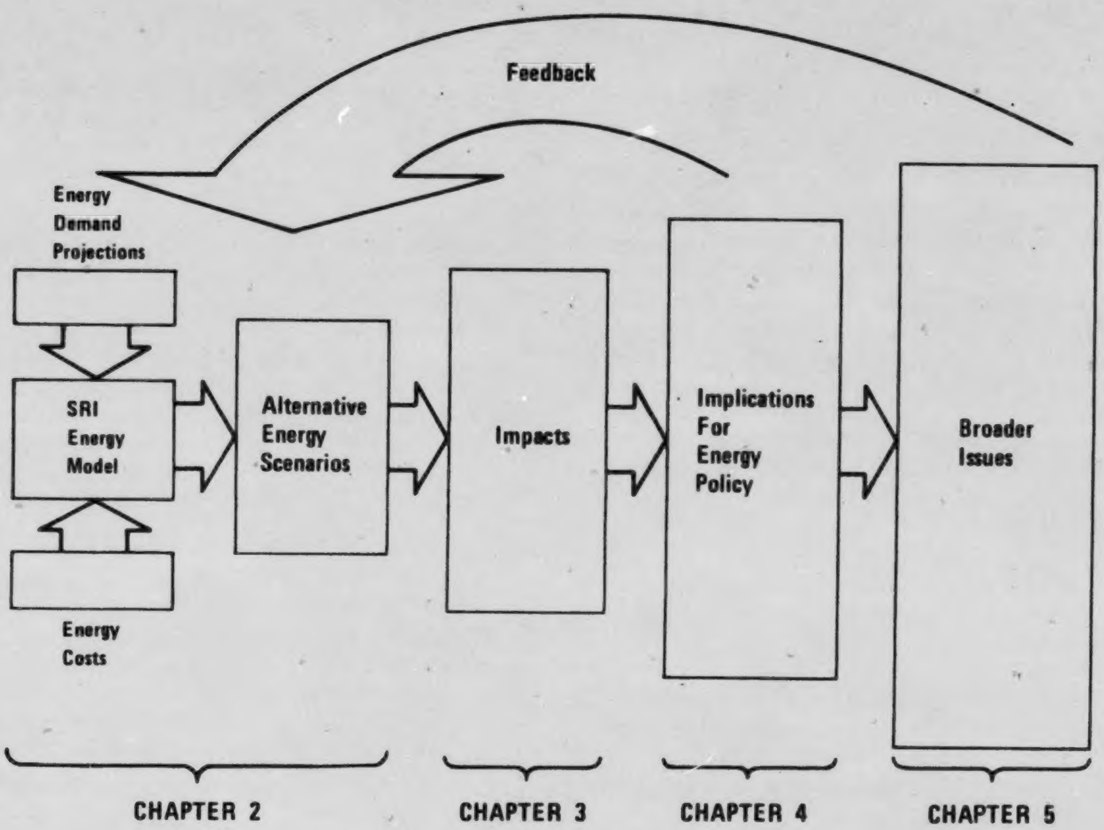


Figure 1-10 Method of Approach and Organization of the Report

amalgam of the quantitative and the qualitative. This second step is described in Chapter 3.

Finally, it was necessary to identify the policy options and key issues that emerged from Chapters 2 and 3, and this we do in Chapter 4. But these policy options do not stand alone. Energy policies interweave with the major issues that face society—they are not isolated from the rest of decision making. Furthermore, the consequences of energy decisions often appear in the weekly sermon as well as on Wall Street. What is an economic and technological issue to one observer is a moral choice to another, and to still others a "Faustian" bargain. These differing perceptions—the profoundly different ways in which different observers perceive the same basic facts lead different observers to entirely different conclusions; they are "seeing different realities" while looking at the same energy facts.

We concluded that we were encountering a phenomenon that lay much deeper than simply the interests of different observers. Rather, we had to analyze the whole-pattern ways in which observers see reality—or better still, the ways in which observers define reality. In some way we needed to assess the significance that these different perceptual frameworks will have on the energy debate.

These were the most difficult conceptual issues with which we dealt. There were no yardsticks such as dollars per million Btu with which to frame and measure these issues, and yet they often transcended the more quantitative in their descriptive power. It is in Chapter 5 that we analyzed these problems. They are not resolved, but posed; they literally define the alternative paradigms of the uncertain future in which the roles for solar energy are to be determined.

In the conduct of this study and in the presentation of our results our role as been as analysts, not as decision-makers. Our function has been to conduct research, not to advocate positions. We acknowledge that the distinctions sometime blur, but we hope we have presented the results in such a way that each reader can test the feasibility, plausibility, and desirability of the alternative futures in this report from their own perspectives and points of view.

2 SOLAR MARKET SHARE ANALYSIS AND THE ENERGY SCENARIOS

If one is to assess the potential the solar technologies have for meeting the nation's needs for energy, it is necessary to analyze the technologies within the broader framework of the total U.S. energy system. It is important to know how the ERDA-49 program compares to alternative projections in which (1) the mix of solar technologies is different—e.g., more solar heating and less solar electricity, (2) the mix of solar and nonsolar technologies is different, and (3) the overall demand for energy is less than or more than that assumed in the ERDA-49 projections. In other words, the study must examine a number of alternative energy projections and make explicit how much solar energy is to be supplied by technology and by region, and how the remainder of the nation's energy supply is to be provided.

It is at this point, however, that one must resolve the methodological problems. It is quite straightforward to write a history of the U.S. energy system and of past energy prices. It is another matter altogether to peer into the future. Energy technologies that are in use today may become obsolete in the future. New technologies that may take over are in many cases, only ideas on today's drawing boards. Technological breakthroughs and cost reductions through mass production may or may not materialize. There is uncertainty regarding the world reserves of fossil and nuclear fuels and of critical materials. Future prices of various energy forms will depend in part upon U.S. and state tax policies and regulations and upon the actions of foreign governments. These uncertainties affect, in turn, the ability to project the future demand for energy.

This study approached these problems in two steps. The first was to treat future technologies and their costs and future levels of energy use as variables—that is, the study analyzed a range of future energy- economics and future patterns of energy use. This parametric approach allowed us to assess the likely changes in market share under different assumptions of future energy costs.

For any specific set of input assumptions, however, it is possible to postulate specific outcomes. Most of the energy-related decisions made by society over time are made by individual consumers and in economic institutions (e.g., corporations) by persons acting in roles that assume economic behavior. To the extent that such decisions are made with economic rationality and based on economic criteria (e.g., choosing the cheapest available supply), they can be simulated in a computer-based model. Such models can be useful because they permit the simultaneous consideration of large number of variables. This study has used an energy model developed at SRI to simulate this functioning of the marketplace.

From the literally infinite number of possible assumptions of energy technology costs and energy demand levels, eight sets of assumptions were chosen to explore the range of plausible energy futures. Computer simulations were made for each set of input assumptions resulting in projections over 45 years of specific energy sources to meet each energy need. As part of the simulation, the projected market prices of energy, by energy form on a region-by-region basis, were calculated.

The analysis of these eight energy projections culminated in a rather comprehensive picture of energy alternatives for the U.S., and from the analysis we were able to synthesize three alternatives to explore in depth in this report. These three alternatives are defined briefly below in just enough detail so that we can begin to refer to them in the discussion. Then, as we proceed through this chapter and into the subsequent chapters we shall build them into richer and more descriptive "scenarios."

- The *reference* case assumes a continuation of the thrust of present U.S. energy policy—minimizing energy prices while maintaining growth in energy use at rates moderately below the pre-1973 period. The total energy supply doubles from today's 73 quadrillion Btu (quads) to 145 quads in 2020 and increases further to 198 quads in 2020. Solar energy provides about 11 quads by 2020-5% to 6% of the total energy supply- almost all of it in the areas of solar space heating for rural areas and solar-heated hot water. We assume that consumers make energy choices solely on the basis of relative price. The solar and nonsolar costs assumed for this case are discussed in detail in this chapter and are based upon the best available information.

- The *solar emphasis* case represents the attempt to find a reasonable-cost way to reach the ERDA-49 level of 45 quads of solar energy. We assume, as we do in all three cases, that the choice among sources of energy is based upon relative prices. We calculate the relative improvements in future solar costs that are necessary to increase the total solar market share to the ERDA-49 target. In doing so, we assume the same nuclear and fossil fuel costs that are assumed for the reference case.
- The *low demand* case allows us to explore the consequences of minimizing energy demand rather than maximizing energy supply. We do so by simulating a substantial energy tax, lower interest rates, and changes in lifestyle to encourage energy conservation.

It is important to understand what the energy scenarios in the study do and do not represent. In this study energy projections are not used either for prediction or for planning; instead, they are used to explore a number of alternative futures. A future such as that proposed in ERDA-49 is assessed, and this future is compared with other alternatives. The energy projections of the study represent different energy futures based on alternative assumptions of energy demand levels and energy supply economics. Thus, one or more of these scenarios is likely to appear wildly improbable to different observers. By presenting the results in a parametric fashion, however, we enable each reader to enter the report with his or her own estimates of future energy costs and future energy demand levels and emerge with insights into the implications of his or her own assumptions and the assumptions of others.

To create scenarios which are internally consistent as well as to determine the costs and benefits of moving to solar energy, an energy market share analysis is necessary. This will include an examination of each potential use of solar energy, the relative advantages and disadvantages of solar compared to its likely competitors for that use, and the measures that would be necessary to induce energy users to switch to solar energy. Such a market share analysis is carried out in this chapter. It assesses the initial impacts of solar energy use and provides a basis for assessing other potential impacts in the following chapters.

The chapter begins with a general introduction to how energy markets work with an emphasis on three primary factors—relative price, demand, and government policy. We proceeded to examine the primary potential solar markets—residential/commercial space heating and water heating, industrial and agricultural heating, fuels from biomass, base load electricity, and intermediate load electricity. Finally, we chose three sets of resource economics, process economics, and demand assumptions to create the three comparison cases—reference, solar emphasis, and low demand.

A. ENERGY ACCOUNTING SYSTEMS

Energy comes in many forms and is used in many ways, and ultimately we account for all types of energy in terms of heat-equivalents measured in terms of British thermal units (Btu). One British thermal unit of heat is sufficient to raise the temperature of one pound of water one degree Fahrenheit. A Btu is so small that we normally speak of a million (10^6) Btu or a quadrillion (10^{15}) Btu (or a quad). The United States uses over 70 quads of energy a year and the average household uses about 60 million Btu a year for space heating. (Statistical Abstract, 1975)

Some forms of energy traditionally use other accounting units. Electricity is commonly accounted for in kilowatt-hours (kWh). One kilowatt-hour is equivalent to 3,412 Btu. Natural gas is commonly accounted for in terms of thousand cubic feet. One thousand cubic feet of natural gas contains about one million Btu of energy. Oil is normally accounted for in barrels. One barrel equals 42 gallons and contains about 6 million Btu. Coal is accounted for in tons. One ton of coal contains from 16 million Btu for western, sub-bituminous coal to 27 million Btu for eastern coal.

Energy starts as primary energy—natural gas, crude oil, coal, falling water, uranium, or sunlight. About 75% of U.S. energy now comes from oil and natural gas. (Statistical Abstract, 1975) Most primary energy is converted into energy products, either electricity or oil refinery products. In accordance with the laws of thermodynamics, energy is "lost" in many conversion processes. For example, for every three quads of coal burned by an electricity generating plant, two quads are lost as waste heat, and only one quad of electricity is produced. In the future, we are likely to convert coal–our most abundant fossil energy resource–into synthetic oil or gas. This conversion process produces about two units of oil or gas for every three units of coal comsumed. Primary energy and the intermediate energy products are used in several ways-to generate heat, to generate mechanical motion, or as chemical feedstocks. An example of the use of a feedstock is the manufacture of synthetic materials, such as nylon from oil or plastic from natural gas. This final stage of energy conversion is usable energy. As in earlier conversions, still more energy is lost at this final stage. For example it takes about 4.5 quads of coal to make 3 quads of synthetic gas, and the 3 quads of synthetic gas are needed to make 2 quads of hot water. Overall, the United States uses about 73 quads of primary energy annually to provide 40 quads of usable energy. (Statistical Abstract, 1975)

There is no single system of units in use for accounting of these many forms of energy. Because this report has been written to communicate to as broad an audience as possible, the approach we have taken is as follows: we have expressed energy in terms of heat-equivalent units (Btu) as often as possible, as well as in the more familiar units (e.g., kilowatt-hours and barrels of oil). We also have tried to express units in metric equivalents whenever possible without arbitrarily imposing data on the reader in units with which no one is familiar. For example, many of the graphs are in both Btu and joules or exajoules. We have tried to strike a balance between familiar systems of units on the one hand and the nation's eventual destination in the metric system on the other.

It is not at all clear how to account for solar energy use. U.S. families used about 2.3 quads of home hot water in 1975. About 3.5 quads of natural gas and electricity were required to produce this hot water because considerable heat energy is lost at the water heater. It takes roughly 3 quads of primary energy (such as coal, oil or gas) to produce 1 quad of electricity. When these electric conversion losses are counted, it takes about 4 quads of primary energy to supply 2.3 quads of residential hot water. With present systems, it would take between 3 and 4 quads of sunlight to supply 2.3 quads of hot water. Because sunlight is "free" and "renewable," however, there is little point in accounting for the amount of sunlight "lost" or "wasted." For this reason, solar energy is usually accounted for in terms of the amount of fossil fuels saved, or fossil fuel equivalent (ffe). This concept is important because future gas or liquid fuels will come from relatively inefficient synthetic production processes. A solar system providing a Btu of heat would save about 1.7 Btu of natural gas today. In 2020 that gas would be made from coal so that the solar system would save 3 Btu of coal. Even though natural gas is mixed with the synthetic gas, by 2020 *virtually all the new sources of gas* (the *marginal* source as we described earlier) will be coming from coal (Cazalet, 1975). Therefore, we will account for solar energy in terms of primary fuel saved from the marginal resource–the least efficient, most costly new source of energy for which solar substitutes. This accounting concept for solar energy will be used throughout the report.

B. HOW DOES THE ENERGY MARKET WORK?

In many respects, energy is like any other economic commodity. Millions of consumers purchase gasoline, natural gas, and electricity from hundreds of utilities and producers. However, the energy market has a number of unique features.

1. Energy Demand

Energy consumption is commonly divided into three use sectors: industrial, residential and commercial, and transportation. The industrial sector is over 35% of the total, and is likely to be the fastest growing energy use. Transportation uses about 40% of all energy-three-fourths of this is for automobilies–but auto use will grow slowly as the new federal automobile mileage standards are implemented. Residential energy use–25% of the total–is mostly for space heating and water heating, and this is the slowest growing energy use. There is great disagreement about the future growth of energy use. Estimates range from less than 100 quads to over 200 quads of primary energy use by the United States by 2000 FEA, 1976. We will use two levels of demand for this analysis. A low demand, high conservation level (energy use rises to 100 quads in 2020) calculated by us for this study, and a reference level growing to 145 quads in 2000 and 200 quads in 2020 adapted from previous SRI calculations.* (This reference demand level is slightly below the ERDA-49 level in the year 2000 and slightly above the ERDA-49 level in the year 2020.)

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*Note: More complete documentation of the energy network, demand, and process economic data base of the SRI energy model will be published by SRI in March 1977 in connection with work done for the Electric Power Research Institute.

Traditionally, energy has been a relatively utilitarian product; we have not needed to worry about style changes in gasoline or do extensive surveys on the consumer's favorite color of electricity. Therefore, for the reference case we assume that in the long run consumers purchase the least expensive form of energy that can perform a specific task. Also, we assume that consumers purchase less energy as energy prices rise. In other scenarios we will explore how non-price related consumer attitudes may come to play a greater role in energy demand.

2. Resource Economics

Because energy goes through such complex stages from primary resource to usable energy, the economics of energy supply are equally complex. The first stage is resource economics. Most energy resources now in use are fossil resources. Although most nonenergy products are priced at a level close to their cost of production, including modest profits, fossil energy resources can be priced well above that level. The reason is that prices for fossil energy resources (as is true for other mineral resources) must be set at whatever level is necessary to make it profitable to discover and pump or mine the *marginal* resource, i.e., the resource at the margin.* For example, as demand for oil increases, the price must increase to bring on more and more expensive wells. A few Texas and Louisiana oil fields are so easy to tap that it would be profitable to pump oil at $4 or $5 a barrel. However, these fields are not large enough to come close to meeting demand so prices are bid up to a level high enough that demand decreases somewhat and, more importantly, larger and more expensive supplies are tapped until total supply and demand are equal. At the present U. S. domestic price of about $8 a barrel, the owners of the few wells that could produce profitably at $4 a barrel could obviously make high profits (assuming no price controls). On the other hand, this price is not high enough to bring on enough new oil wells (i.e., the marginal resource) to even maintain total domestic oil production levels.

Extra profits going to owners of superior resources are not limited to energy or mining. In agriculture there was such world-wide demand for corn in 1974 that the price was bid up to a level where corn was grown on marginal land even in the Dakotas, Northern Minnesota, and elsewhere. At a price sufficient to risk planting corn in the Dakotas, farmers owning good Iowa and Illinois corn land were doing so well that Illinois corn land prices were bid up to $2500 or $3000 an acre from the previous $1000 an acre. This relationship between the amount of resource available at different prices is known as a "resource curve," and the extra profits going to owners of the best wells, mines, or land are known as "economic rent" or "royalties." (See Brannon, 1974)

A second component of energy prices is what is best called "scarcity rent." (Cazalet, 1975) Because resource owners know that fossil energy resources are being steadily consumed, and they anticipate that additional supplies will be available only at much higher prices, they expect future prices to increase. Therefore, there is some current price, even above costs of production for current marginal resources at which they would rather wait and not sell. This price is determined by how quickly they expect future prices to increase, how certain they are about future increases, and how willing they are to wait. This willingness to wait is expressed as an interest, or discount rate. Thus, resource owners who are unwilling to wait are using a high discount rate—they prefer having $1 today to $2 in the future.

3. Process Economics

Having considered the price of the basic resource, we need now to examine the costs of the many alternative conversion, transportation, and end use processes. These include both initial construction and continuing operation cost. For each category of energy use in each location there will be one combination of primary resource, transportation, intermediate conversion, and end use conversion which will deliver the cheapest energy. For example, in California in 1975 the cheapest hot water probably comes from a gas hot water heater using natural gas coming by pipeline from New Mexico. In Tennessee, the cheapest hot water comes from electric hot water heaters using electricity generated from coal dug in Kentucky and shipped by rail to Tennessee. Of course, the economics of many of these processes will change over time. Technical progress will improve the efficiency of some processes, while many basic resources will increase in cost as the best mines and oil fields are exhausted. In addition, new technologies will appear as they become commercially viable.

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*Note: A large, integrated oil producer owning both low-cost and high-cost wells might be willing to sell oil at average prices, but a large share of the more costly wells are owned by small producers who will not produce except at high prices. This is a strange situation where in the short run oil prices might be kept lower if there were less competition—only large producers who could afford to sell at an average price.

4. Energy Transportation

In a nation as large as the United States, each region will have very different sets of energy supplies and demand. For some energy sources, coal for instance, transportation costs may be more important than basic resource costs. Because transportation and geographic variation are so important, energy analysis must be done regionally rather than with national totals. We will use the supply and demand regions shown in Figure 2-1.

5. Energy Modeling

Analyzing all these technical and economic aspects of energy markets is impossible without a computer model of the energy sector. We used the SRI energy model which is particularly well adapted to analysis of the market shares of the different energy sources, decades into the future. The model uses estimates of quantities of resources in the ground, costs of extraction, transportation, and conversion to usable energy to calculate energy costs in 1975 (uninflated) dollars.* The model then determines the cheapest means of meeting 22 types of assumed energy demand in each of nine geographic regions. This involves thousands of calculations, but the result is a projection of the lowest cost way of supplying energy for all the different demands for the next half century. The model is an important tool to understand how much solar energy consumers might use under different conditions. However, it should be emphasized that all the calculations of the model depend on the input assumptions such as those discussed above.

We must emphasize that this analysis is *not* based on simple straight line projection of future oil and gas costs. Oil costs have risen rapidly over the recent past, but it is unlikely that such increases can continue for very long. At oil costs above $20 to $30 a barrel, most analysts agree that synthetic oil and gas production from coal becomes competitive. (Cazalet, 1975) This represents a real ceiling on oil and gas costs. At a steady 10% annual increase, for example, oil would cost more than $150/barrel by 2000. Because such estimates are clearly above competitive synthetic gas/oil costs, using such constant rates of increase could be misleading.

The model simulations lead to several important conclusions:

1 Even with extensive offshore and Alaskan drilling, U.S. oil and natural gas production is likely to decline over the next 50 years even if oil sells for $20 per barrel.

2 Coal is likely to dominate energy supplies for at least the next 50 years.

3 So much western coal exists that billions of tons per year can be mined at a steady $10 to $12 per ton through the year 2020.

4 Coal can be converted to synthetic oil and gas, but only at a cost at least double or triple that of today's oil and natural gas. At these higher prices, coal can provide enough synthetic oil and gas to last for more than a century.

We shall discuss these and other conclusions in the sections to follow.

6. Government Intervention

Heavy government intervention is an important but unpredictable special attribute of energy markets. Governments use both direct intervention, such as previous U.S. oil import quotas, and economic incentives, such as tax advantages and subsidies, to direct the U.S. energy market. (Brannan, 1974) If all the laws that apply solely to the energy market were abolished, the U.S. energy picture would change dramatically. United States natural gas prices would rise substantially and the entire energy supply/demand mix would change. Present government interventions include the following:

Federal

1. Natural gas price ceilings on a gas sold out- of-state.
2. Domestic oil price ceilings.
3. Allocation of oil to refineries.
4. Special tax incentives for coal mining and oil drilling.

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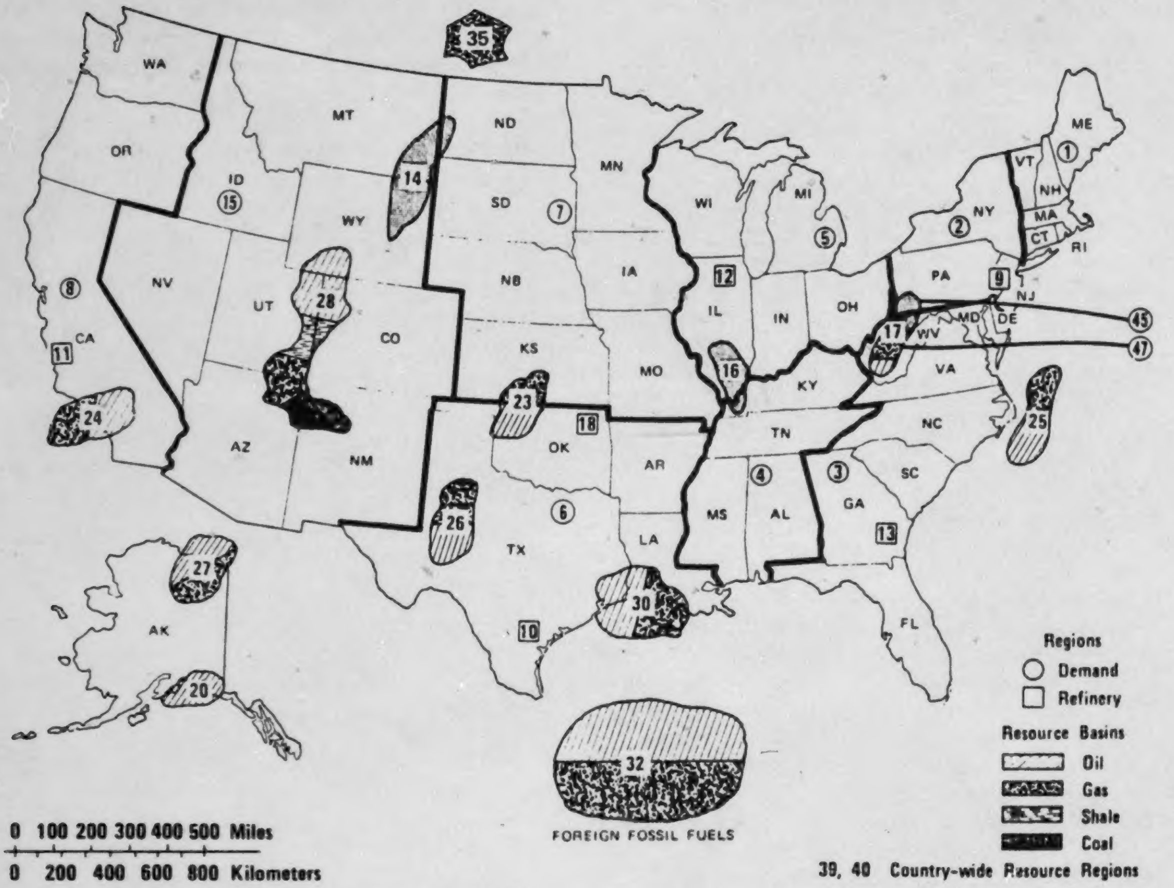
*The model also calculates future prices based upon whatever assumption of inflation rate is chosen. In this report we adjust all costs and prices back to 1975 dollars so the comparisons to today are not confused by inflation.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WV
VA
NV
UT
CO
KS
MO
KY
CA
AZ
NM
OK
AR
TN
NC
SC
GA
AL
MS
LA
TX
FL
AK
FOREIGN FOSSIL FUELS
0 100 200 300 400 500 Miles
0 200 400 600 800 Kilometers
Regions
○ Demand
□ Refinery
Resource Basins
▨ Oil
▩ Gas
▧ Shale
■ Coal
39, 40 Country-wide Resource Regions

DEMAND REGIONS

1. New England
2. Middle Atlantic
3. South Atlantic
4. East South Central
5. East North Central
6. West South Central
7. West North Central
8. Pacific
15. Mountain
45. Location of U.S. Metallurgical Coal Demand
47. Location of Coal Export Demand

REFINERY REGIONS

9. Philadelphia
10. Gulf Coast Port
11. West Coast Port
12. Chicago
13. South East Port
18. West North Central

RESOURCE REGIONS

14. Great Plains Coal
16. Interior Coal
17. Appalachia Coal, Oil & Gas
20. South Alaska Oil & Gas
23. Midcontinent Oil & Gas
24. Pacific Coast Oil & Gas
25. Atlantic Offshore Oil & Gas
26. West Texas Oil & Gas
27. North Alaska Oil & Gas
28. Rocky Mountain Coal, Oil, Oil Shale & Gas
30. Gulf Coast Oil & Gas
32. Point of origin for imported fossil fuels
35. Point of origin for Canadian gas
39. Point of origin for nuclear fuels
40. Secondary material location

Figure 2-1 Demand, Resource, and Refinery Regions

5. Multi-billion federal research and development support for new energy processes.

6. Federal insurance for nuclear power.

7. Federal production of enriched uranium.

8. Federal ownership of large hydro/fossil electric systems including Bonneville, TVA, and others.

9. Ownership of offshore oil, nearly all oil shale, and much of western coal.

State

1. Control of electric rates.

2. Control of some gas prices.

3. Control of generating plant and refinery sites, and port facilities.

4. Ownership of some large power systems such as New York Power Authority.

Local

1. Power system ownership.

Foreign

1. Control of oil import prices.

Because this is a report about events over the next 50 years, and guessing government policy over such a time period is quite impracticable, our analysis emphasizes the fundamental technical and economic factors in energy markets. No model can predict federal policy. The basic analytic framework assumes free market prices for energy. Alternative government energy policies are then discussed insofar as they might affect the market and solar energy impacts.

C. SOLAR ENERGY MARKETS

From this basic explanation of how to account for energy and how energy markets work, we now proceed to the solar energy analysis. This analysis will answer the questions: How is solar energy most likely to be used? For what nonsolar energy sources and processes will solar energy substitute? and What incentives might be necessary to induce more use of solar energy?

1. Residential Water Heating

Solar water heating is an attractive energy option for numerous markets including single-family homes, low-rise apartments, and commercial establishments. The solar water heating system typically consists of a solar collector panel that either directly warms household water or uses a heat-transfer medium to indirectly heat the water. Such systems were once used throughout Florida, and solar water heaters are still used extensively in Israel and Japan. Both the amount of sunlight and the total demands for energy vary geographically so the potential for solar markets must be analyzed on a region-by-region basis. Each solar water heating system simulated in this study is assumed to provide about 70% of the total energy required from sunlight and back-up gas or electric heaters provide the rest.

Figure 2-2 shows the relative costs of such a system where it would be the least expensive, the Southeast; Figure 2-3 shows the relative cost where it would be most expensive—the Northeast. These costs include operation (including backup fuel), maintenance, and loan payment. Investment costs shown are for systems installed beginning in 1978. Over time these costs are simulated to fall to 80% of their initial value. In both regions, the solar system would be the lowest-cost system for new installations by the early 1980s. Based on the reference case cost assumptions, we anticipate solar water heating would be used for most new water heating installations within about 5 years.

The data on Figures 2-2 and 2-3 show that an economically rational consumer should prefer solar water heating. However, there may be many obstacles to most consumers accepting solar water heaters. First of all, home buyers are extremely sensitive to the initial cost of a house. Half of all homes are now built with electric heat, often because its installation costs are so low even though the monthly heating bills might be dramatically higher than the alternatives. Secondly, even an interested consumer might have trouble getting a loan for a solar heater. The final problem is that a potential buyer who expects to move and sell the house in 5 years would fear that the extra cost of the solar system would not be reflected in the re-sale price of the home.

We use a 15% interest rate for all energy processes in the residential/commercial sector. If lower interest rates were available, capital intensive processes, such as solar, would differentially benefit.

Figure 2-4 shows how the solar market share in 2020 varies as a function of the projected prices of the two competitors–electricity and gas. For example, if electricity delivered to the residential consumer costs 5¢ per kWh (slightly above the 1975 average), (BLS, 1976) then solar systems would provide over 80% of all water heating. Because 30% of the solar system is gas or electric backup, 80% solar system use means 56% of the water heating energy would come from solar energy. Because electricity already costs many consumers more than 5¢ per kWh, and has been rising steadily in price, (BLS, 1976) there is little likelihood that future electricity prices could decline enough for electric water heating costs to be less than solar water heating. Gas, on the other hand, now costs only $1.50 to $2.50 per million Btu (or per 1000 cubic feet) for residential customers in most of the nation (outside the Northeastern region); (BLS, 1976) therefore, solar water heating would become competitive only if there is a substantial increase in the price of gas.

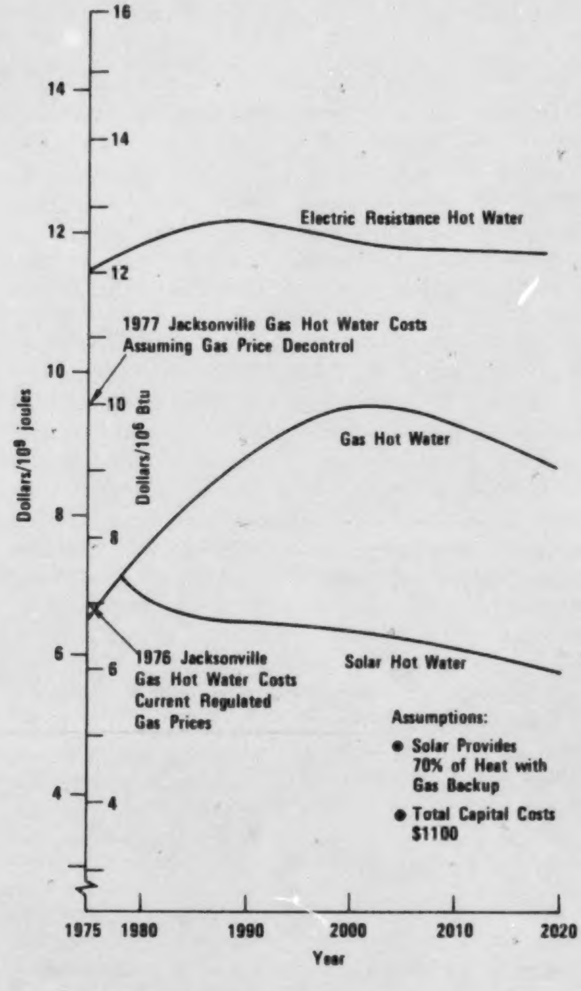


Figure 2-2 Residential Hot Water Costs--South Atlantic

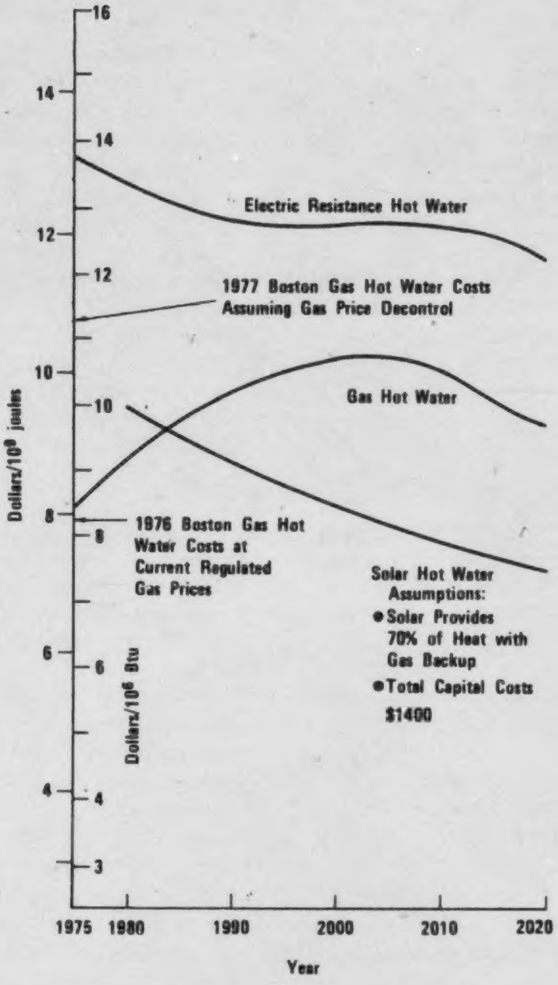


Figure 2-3 Residential Hot Water Costs--New England

Interstate natural gas prices are currently kept low by federal regulation. Recently the Federal Power Commission (FPC) took action that would raise the price to the consumer by about $1.00 per 10⁶ Btu over 10 years or more. But this action may be reversed by the courts or Congress. (Forbes, 1977) The price of gas not subject to federal price ceilings, the "free market price," is close to $3.50 per 10⁶ Btu for the residential customers in some states. Solar water heating simply cannot compete with $1.50 or $2.50 gas. If gas prices were deregulated, it appears that the solar water heating industry would become viable with little or no additional help.

Because gas price deregulation has proved so unpalatable, many parts of the country ration scarce natural gas by refusing new gas hookups. This policy many be politically viable, but it has some severe economic consequences. Although this policy pushes consumers toward solar energy, it also forces them to use more expensive electric backup. Secondly, this policy provides no incentive to existing homeowners to add insulation and conserve gas. As long as gas is cheap, why should they bother?

Because natural gas, or high-Btu synthetic gas made from coal, is the strongest competitor with solar energy in most solar markets, we present a more detailed explanation of the gas market. Natural gas is now the second largest sector of U.S. energy and provides 19 quads or about 25% of the total supply (see Figure 1-2). Natural gas is clean, and the federally regulated portion of the supply is much cheaper than electricity or oil and is competitive even with coal. The Canadians now sell gas to the United States at $1.88 per 1000 cubic feet, (PG&E, 1977) but the regulated price for gas from old U.S. fields was only 52¢ per 1000 cubic feet until recent FPC action (which could be reversed). (Forbes, 1977) Because of high past usage, encouraged in part by low prices, it is unlikely that current natural gas production rates can be maintained much longer. Synthetic gas from coal (SNG) appears to be the least costly source of substitute natural gas. Using advanced conversion processes, SNG could be produced for $2.50 per 1000 cubic feet (10^6 Btu) starting in 1990. After distribution costs, the cost to the consumer would be about $3.50/$10^6$Btu. This requires low-sulfur coal as input at 50¢ to 60¢ per 10^6 Btu ($8 to $10 per ton), 65% conversion efficiency from coal to gas, operation and maintenance costs of 88¢ per 1000 cubic feet, and a capital cost of about $8.55 per 1000 cubic feet of daily capacity. This set of estimates is the *single most important economic assumption* for predicting future solar energy market shares for hot water heating and, as we shall see, for several other markets as well.

Table 2-1 shows demand projections for residential/commercial miscellaneous heat (70% of which is for water heating and the remainder is for cooking and drying).

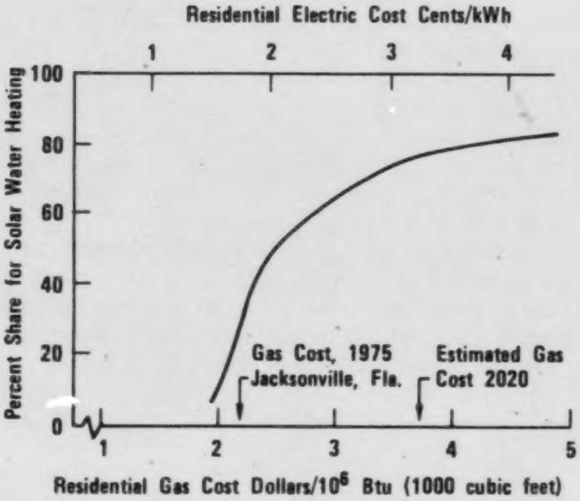


Figure 2-4 Solar System Market Share--Residential Hot Water Market (South Atlantic--2020)

Table 2-2 shows how much of this miscellaneous heating is supplied by solar energy. *Low* corresponds to the low demand scenario, *high* corresponds to the reference and solar emphasis scenarios. Because solar energy systems capture 80% of the miscellaneous heat market by 2020 without special incentives, it is unlikely that further cost reductions would yield much additional market penetration. Rather, the market will be limited by other factors such as the difficulty in using solar on urban high- rise buildings, or in homes that are located on north- facing hillsides, and so on.

Table 2-2 also shows the degree of regional variation in solar energy use and the slow penetration of even an economically superior product such as solar water heating.

2. Residential and Commercial Space Heating

Residential and commercial space heating is an important but relatively slow growing demand sector. As for the water heating market, two demand estimates are provided—one from a high-price, high-conservation assumption, and the other from a higher demand assumption. (Table 2-3)

Solar space heating systems are commonly divided into "active" and "passive." Although the distinction between these two is not always sharp, active systems usually involve a collector to absorb the solar energy, a heat-transfer fluid to carry the heat either to storage or

TABLE 2-1

ENERGY DEMAND-RESIDENTIAL/COMMERCIAL MISCELLANEOUS HEAT (in quads)

	1975	1985		2000		2020	
	Actual	Low	High	Low	High	Low	High
Usable energy	2.3	2.8	3.3	2.9	4.6	2.9	6.3
Estimated primary energy needed	4.0	5.6	7	9.0	12	5	15

to be distributed, a storage system to store thermal energy for later use, and a system of pumps and controls to direct the flow of heat as needed. Passive systems, on the other hand, incorporate a series of architectural principles that maximize solar heat gain during the winter and minimize the solar heat gain during the summer. These principles can include large south-facing windows, shutters, overhangs, walls of high thermal inertia, and so forth. In addition, passive systems and most active systems incorporate some form of auxiliary heat to provide for prolonged periods of low insolation and/or high heat demand. These auxiliary systems can be any of a variety of traditional heating systems including combustion furnaces (gas, oil, coal), electrical resistance heaters, wood burning stoves and fireplaces, and so forth.

Although solar heating systems generally share these common principles and components, in actual practice they can be assembled in innumerable ways to result in many types of systems. For example, collectors can be flat metallic, focusing, or newly evolving "moderately concentrating." Heat-transfer fluids can be air, water, or special organic fluids. Storage systems can be rocks, water, or even more exotic phase-changing material (such as paraffin waxes). No one system has evolved from all these possible combinations as the "best." Indeed, it is likely that as experience is gained, a variety of systems will evolve, each best suited to a unique niche of building type and geographical location.

In addition to these traditional solar heating systems concepts, several "hybrid" systems are being developed to use solar heat in conjunction with heat pumps and air conditioners.

Solar/heat pump combinations take two forms: solar assisted and solar activated. Solar-assisted heat pumps use solar energy to produce a moderate temperature heat source (e.g., 50°F) from which heat can be extracted by a heat pump. The advantage of this

TABLE 2-2

SOLAR MARKET SHARE–RESIDENTIAL/COMMERCIAL MISCELLANEOUS HEAT

(In quads - Primary Fossil Equivalents)

REGION	1985		2000		2020	
	Solar and Reference	Low Demand	Solar and Reference	Low Demand	Solar and Reference	Low Demand
New England	–	--	0.2	0.1	0.4	0.2
Middle Atlantic	0.1	0.1	0.5	0.3	1.3	0.7
Southeast	0.1	0.1	0.5	0.3	0.9	0.5
Mid-South	0.1	0.1	0.3	0.2	0.5	0.3
North Central	0.1	0.1	0.7	0.5	1.6	0.8
South Central	0.1	0.1	0.4	0.3	0.7	0.4
Mid West	0.1	0.1	0.3	0.2	0.6	0.3
Pacific Coast	0.1	0.1	0.5	0.3	1.2	0.6
Rocky Mountain	--	--	0.1	0.1	0.3	0.2
TOTAL	0.7	0.7	3.4	2.3	7.6	4.0

TABLE 2-3

ENERGY DEMAND-RESIDENTIAL/COMMERCIAL SPACE HEATING (in quads)

	1975	1985		2000		2020	
	Actual	Low Demand	Solar Emphasis and Reference	Low Demand	Solar Emphasis and Reference	Low Demand	Solar Emphasis and Reference
Usable space heat							
Urban	3.6	4.8	4.3	4.0	5.6	4.8	7.0
Rural	1.2	1.2	1.3	1.3	1.4	1.4	1.6
TOTAL	4.8	6.0	5.6	5.3	7.0	6.2	8.6
Estimated primary energy needed	12	15	15	14	18	17	24

system is that the heat pump can maintain a high coefficient of performance even though the outside air might drop to very low temperatures (conventional heat pumps cannot extract heat efficiently from a heat source below about 30°F).

Solar-activated heat pumps use solar energy to drive a heat engine that in turn drives a mechanical heat pump. This system (i.e., the heat engine and heat pump combination) can provide both heating and cooling because the heat pump can be reversed simply to provide summer cooling.

Air conditioning (cooling) can also be provided by using solar energy as a heat source for an absorption refrigeration system. This principle is well established as absorption refrigeration units have found widespread use in both residential and commercial markets. However, the transfer of this technology to a solar system is difficult because existing absorption systems have been developed to be used with the high temperatures available from combustion processes. Development work is underway to modify these systems to utilize more efficiently the lower temperatures (e.g., below 200°F) that can be economically obtained from most solar collectors. Because solar cooling is so expensive, at present, we estimated no market penetration for solar cooling systems.

The cost of residential solar heating systems is highly variable and widely misunderstood. Very low cost systems (e.g., $2,000 to $4,000) that have been reported sometimes neglect the donated labor costs of the homeowner/inventor, utilize recycled materials that might not be widely available, have design features that many homeowners and/or building codes would find aesthetically unacceptable, and/or deliver only modest amounts of solar-thermal energy. At the other extreme, very elaborate, custom-engineered solar heating and cooling systems have been installed that cost over $10,000. Neither of these extremes is likely to be an accurate representation of the type of systems that will achieve widespread commercial use. Because there is considerable confusion regarding solar heating system cost, some clarification needs to be made. Current solar collectors can range from $2.00 per ft^2 (for example, low temperature plastic types) to over $20.00 per ft^2 (for example some higher performance, evacuated tube types). Supporting equipment (auxiliary heater, thermal storage, ducting, and controls) typically costs from $1,000 to $3,000. A common practice when quoting solar heating system costs is to calculate dollars per ft^2 figure based on total installed system cost divided by the collector area. This can be confusing because the number quoted on this basis will be larger (up to twice as large) than the actual cost of the collectors themselves (on a ft^2 basis).

Solar systems can structurally complicate a house (heavy solar collectors might require stronger roof reinforcement), so that it is necessary to allocate such costs as debits to the solar energy systems. Alternatively, it is possible to achieve some cost savings by obtaining dual functions from the solar system (e.g., collectors acting as roof surface). It is important not to place significance upon facts which in and of themselves supply incomplete information (e.g., collector costs in dollars per ft^2). Economically, the information that is more important is the total net system cost (i.e., including backup, installation, and with all debits and credits accounted) and the usable heat delivered by that system over a typical year.

For the evaluations used in this report, a baseline solar residential system costing $4,000 has been selected. Over time this installed cost is simulated to fall

20%. As discussed later, it has been assumed that, on the West Coast, this residential system would supply 45 million Btu per year (70% of this is derived from the solar energy component of the system). We use solar heating systems with different total heating capacities and backup shares for the nine regions. Commercial solar systems are scaled up from residential systems in proportion to their larger demand. This modeled system is considered to be generic and might, in practice, be either active or passive, conventional, or heat pump.

Solar residential/commercial space heating is not as promising as water heating. The difficulty is that most of the demand is in midwestern and northeastern states at a time of year when cloudy conditions often prevail. Comparative costs for residential heating systems are shown for the Pacific region in Figure 2-5.

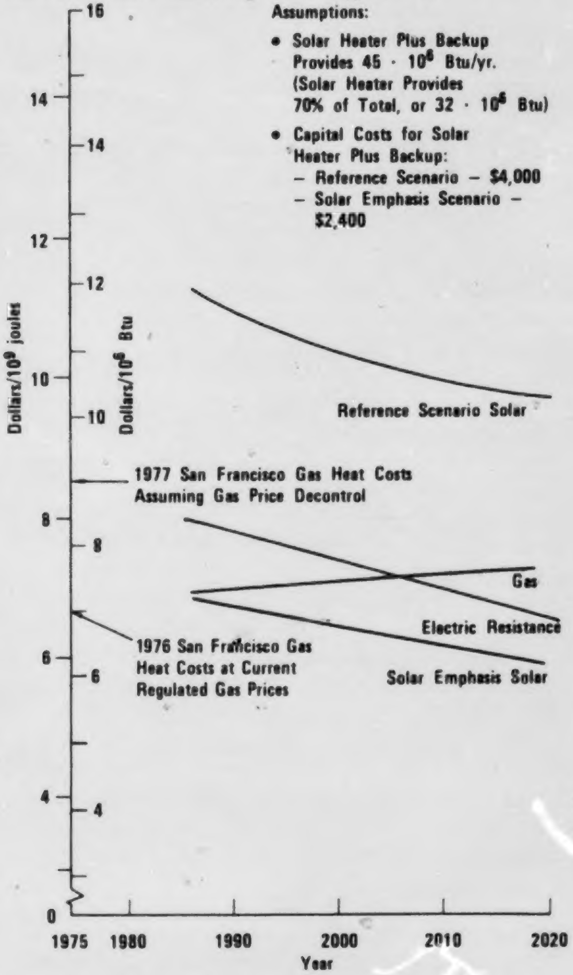


Figure 2-5 Cost of Residential/Commercial Space Heating--Region 8 (Pacific-2020)

The results of these analyses indicate that solar energy could dominate rural space heating. In rural areas, the least expensive heat source, high-Btu gas, is not available because it is too expensive to install gas distribution grids in sparsely populated areas. Such areas rely on more expensive liquefied petroleum gas (LPG), propane, fuel oil, or electricity for heating. A solar heating system is likely to be slightly less expensive than any of these alternatives by the 1980s. Given the naturally slow changeover as old heating systems and homes are replaced, solar should dominate this market by 2000. However, as Figure 2-6 shows, unexpectedly high solar costs and/or unexpectedly low nonsolar costs could prevent solar market penetration even of the rural heating market.

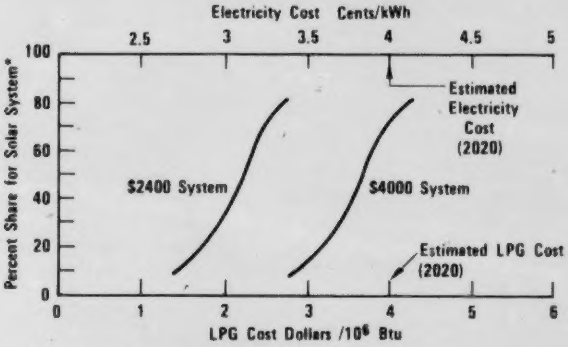


Figure 2-6 Solar System Market Share--Rural Space Heating (2020)

In the larger urban space heating market, solar energy faces the more difficult task of competing with high-Btu gas. In this case, solar energy captures a large share of the market only when residential solar systems cost less that $2,400 (falling 20% over time) or high-Btu gas costs more than $4 per 10^6 Btu and residential electricity costs more than $12 per 10^6 Btu (4¢ per kWh) as shown in Figure 2-7. In the key midwestern and northeastern markets, electricity for home heating often receives preferential low rates because it uses electric generating capacity that would otherwise go unused during winter nights. Such preferential rates are reasonable from the perspectives of electric utilities and state regulatory commissions, and we simulate this factor by reducing residential electric rates by 1¢/kWh ($3/million Btu) for residential heating. The overall result can be assessed from Figure 2-7. The effect of lowering electric rates is to create a more difficult competitive environment for solar heaters.

Even when solar heating is economic, solar penetration of the residential/commercial heating market is likely to proceed very slowly because it is largely limited to new construction. Because new construction equals only about 2% of the housing stock per year, it would take over 50 years to convert all housing to solar heating if 100% of new housing used solar heating systems and the amount of retrofitting was negligible. (Stat. Abstract, 1975) This makes early penetration particularly important for the residential market. Unless special steps are taken, every house built today without solar heat probably cannot be converted to solar economically for its 50 or more year life span.

Present federal/state energy policies in the residential energy market prevent more solar heating even though solar heating should be economically viable by 1985 in much of the country. These policies are:

- Price ceilings on natural gas
- Subsidy of electricity
- Limitations on home mortgage borrowing.

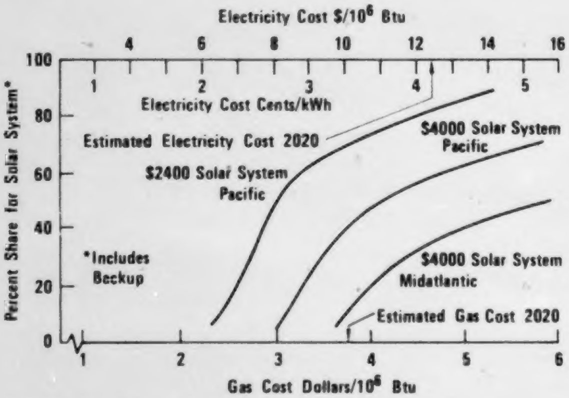


Figure 2-7 **Solar System Market Share--Urban Residential Space Heating (2020)**

The problem of natural gas price ceilings has already been discussed. The problem is just as relevant to space heating as it is for water heating.

The second pertinent federal policy is providing low-priced electricity. Rural electricity is generally provided by the Rural Electrification Administration (REA). REA cooperatives were largely financed by 2% loans, although this rate has increased in recent years (U.S. Budget 1967-1974). Solar energy could compete with normal tax-paying, nonsubsidized interest rate rural electricity, but it cannot successfully compete with subsidized REA electricity. Past federal interest rate subsidies also keep down the price of both urban and rural electricity in two sections of the country that have cheap federal power, the Far West, and the Tennessee Valley area. In both cases, electricity costs are below competitive rates because of past and present low-interest federal loans and direct subsidies. (U.S. Budget, 1976) In some areas, low- price municipal electricity, subsidized through tax exemptions and low-interest, tax-exempt bonds, could also interfere with solar heating market penetration. (Brannan, 1975)

The final set of policies, federal limits on mortgage financing, make it difficult to finance a solar heating system even where the consumer is willing. Because the solar system costs several thousand dollars above the normal price of the house, the purchaser of a home with solar heating will need a larger mortgage. However, federal regulations limit the purchaser's ability to borrow. The Federal National Mortgage Association (FNMA) and the Federal Home Loan Mortgage Corporation (FHLMC) will purchase a mortgage from a bank or savings institution only if that mortgage does not exceed two and one-half times a family's income. Because most banks and savings institutions want to retain the option to sell their mortgages in the face of recurrent "credit crunches", they treat this guideline as a mandatory ceiling on new loans. (Northern Cal Savings, 1976) Most moderate- income home buyers already have difficulty in finding a home whose purchase price is within this ceiling. Even though a solar system might pay for itself in reduced utility bills, which some bankers understand, the federal guideline does not take this factor into account. Therefore, even a willing purchaser of a new home would have to sacrifice the size of the basic house, or pay for the solar system with a larger down payment.

Because of these loan limitations and general consumer unwillingness to make large cash outlays, we used a 15% interest rate to calculate the cost of solar and other heating systems. This problem would be solved by basing the loan ceiling on family income *after* expected utility costs and by using a higher income factor—for example, three times income after utility costs. Such a regulation would reward both well-insulated and solar-heated homes. Using an 8% interest rate instead of 15% is equivalent to dropping the capital cost of a solar system from $4,000 to slightly more than $2,000.

Another potentially important factor, in addition to federal policies, is electric utility pricing policies—that is, charging different rates at different times of year or day or to different types of customers. One of the most difficult problems for utilities is peak-loading—that is providing expensive electric generating capacity that is needed only a few hours a day or a few weeks a year.

Several utility systems are experimenting with a variety of "peak-shaving" techniques–ways of charging higher prices or reducing demand during peak periods. Solar heating could be either helped or hindered by peak- loading pricing schemes. If a solar heating system is designed with electrical backup so that all the solar systems in a city need large amounts of electricity at the same time–creating a new peak-load problem–such solar systems would be charged high peak-load prices for their electricity. On the other hand, if a solar system is designed to reduce peak-loading troubles by, for example, supplying all hot water during the summer, then such a system deserves preferential low rates. Because peak-loading problems differ by geographic area, solar manufacturers could work closely with local utilities to design solar systems that would gain preferential "peak-smoothing" electric rates.

The potential for solar space heating can be summarized as follows: although the northern states have less sunlight, they have such a large heating load per building that the potential for solar heating is greater in the north–the potential, that is, when measured in terms of total Btus of fossil fuels saved–although its percent share is higher in the south.

The residential/commercial sector as a whole is summarized on Table 2-4.

TABLE 2-4

SUMMARY OF SOLAR MARKET SHARES: RURAL AND URBAN SPACE AND MISCELLANEOUS HEATING

Nonsolar Costs Solar Costs	Residential Gas below $3/10^6$ Btu or Residential Electricity below 3¢/kWh	Residential Gas Costs $3.50/10^6$ Btu and Residential Electricity Costs 4¢/kWh	Residential Gas Costs over $4.50/10^6$ Btu and Residential Electricity Costs about 6¢/kWh
Solar Emphasis	Solar supplies some space heating, water heating and rural heat;5-10 quads saved in 2020	Solar dominates rural heating and water heating with much space heating; 15-20 quads saved in 2020	Solar dominates water heating and space heating; 20-30 quads saved in 2020
Reference Costs	Water heating only; 3-6 quads saved in 2020	Solar dominates rural heating and water heating; 8-12 quads saved in 2020	Solar dominates most heating; 15-25 quads saved in 2020
Costs 50% above Reference Case	No solar heating	Water heating only; 2-5 quads saved in 2020	Solar water heating and rural heating; 6-10 quads saved in 2020

3. Industrial/Agricultural Heating

Although many industrial processes require very high temperatures–such as blast furnaces–the single largest industrial use of energy is for relatively low-temperature (below 350∫F) hot water and steam. Much of this is for food processing. Total industrial indirect heat–largely hot water and steam use–is shown in Table 2-5. The solar potential for this market is highly uncertain. Some industrial steam and hot water applications have the advantage of being largely daytime uses–when sunlight is available. Although hot water and home heating are needed in the evening and early morning, some industrial use begins later in the morning and does not continue into the evening.

On the other hand, many industrial plants can achieve high energy efficiency, use waste heat, and are able to directly burn coal. (Direct coal burning was assumed to be a negligible part of the market for residential heating.) It is unlikely that solar can compete with direct burning of coal, even with highly optimistic solar costs.

There is even more confusion in regard to solar costs. MITRE (MITRE, 1976) recently estimated that solar steam systems would cost $8 to $9 per 10^6 Btu; Intertechnology Corporation (ITC) (ITC, 1976) estimated that a solar steam system (with backup) would cost about $4 per 10^6 Btu. As Figure 2-8 shows, even the ITC cost is not competitive with direct burning of coal, and the MITRE cost estimate is well above the cost competitive range of either gas or coal.

The ITC report assumed no direct coal burning for industrial heat as well as extremely high cost of oil–about $50 per barrel in 1975 dollars by the year 2000 (ITC, 1976). With these assumptions, they project 7

TABLE 2-5

INDUSTRIAL/AGRICULTURAL INDIRECT-HEAT DEMAND (in quads)

	1975	1985		2000		2020	
		Low Demand	Reference & Solar Emphasis	Low Demand	Reference & Solar Emphasis	Low Demand	Reference & Solar Emphasis
Useable Energy	5.5	4.5	8.6	5.3	12.9	6.3	16.0
Estimated Primary Energy	7.0	6.0	10.0	7.0	17.0	8.0	24.0

quads of solar steam and hot water production by 2000. For the solar emphasis case we assume solar costs equal to ITC levels, but because we expect coal, oil, and gas prices well below the $50 range, this would lead to only 4 quads of solar primary energy equivalents by 2020.

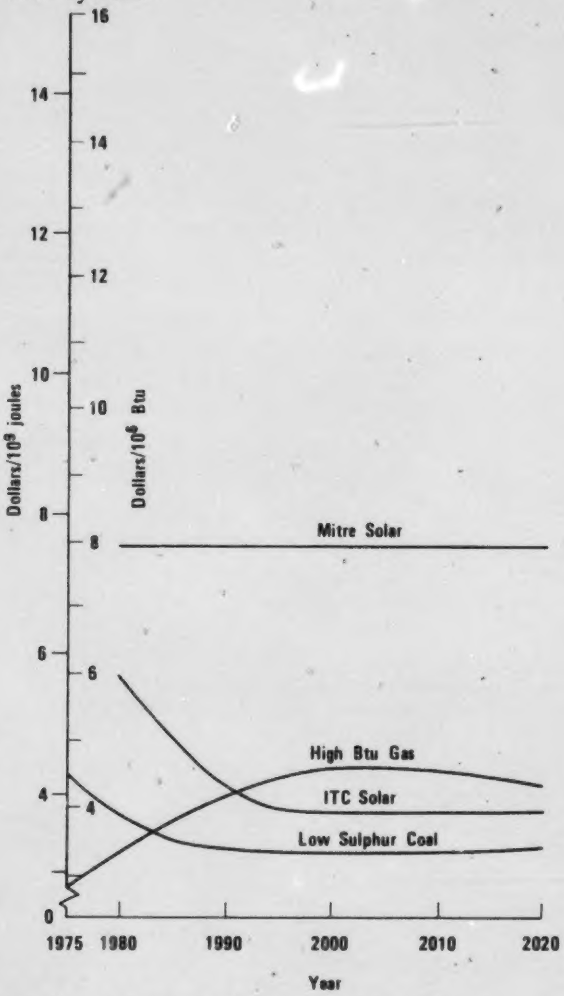


Figure 2-8 Cost of Industrial Steam—Eastern United States

Cost and demand estimates for agricultural crop drying are highly variable and uncertain. However, the fact that high-Btu gas is not available in rural areas and that small-scale coal use on farms would be impracticable makes the farm sector particularly interesting for solar energy use.

4. Biomass

Because green plants capture solar energy by photosynthesis, the extraction of energy from plant material can be viewed as a form of solar energy use. This source, which includes agricultural residues, urban wastes, and specially grown energy crops, is collectively referred to as biomass. Biomass is different from other solar energy sources in that is can be converted to an energy product—high-Btu gas, methanol, or electricity—rather than an end use such as home heating. Biomass can be converted in the same way as coal is, at similar costs, to either gas, methanol, or electricity. Some types of biomass can also be converted to gas with biological digesters or burned along with coal in electric power generation. The most promising of these conversion processes is high-Btu gas from biomass. Biomass is a more limited resource than sunlight because its production relies on arable land. For this reason, biomass is similar to other natural resources such as coal in that the more it is used the more it costs per unit. Relatively inexpensive biomass resource is available from urban wastes (garbage), agriculture residues (manure and stalks), and forest residues (branches and sawdust). Once easily collected biomass is exhausted, collection costs begin to rise, and finally biomass plantations growing trees or sugar cane are necessary (marine biomass appears much more expensive than terrestial biomass). By 2020, estimates are that the first quad of biomass resource will cost $1.00 per million Btu delivered to a collection site. Costs would rise to $1.50/$10^6$Btu for 10 quads per year and to $3.00/$10^6$Btu for 20 quads per year. (Note that this cost is for the collected biomass and does not include the cost of converting the biomass to an energy product). This availability will grow slowly as biomass resource collection systems are established as shown in Table 2-6. This availability of biomass should be compared to the large market for high-Btu gas (natural and synthetic) as shown in Table 2-7.

TABLE 2-6

BIOMASS COLLECTABLE AT $1.50/10^6 Btu
(in quads)

REGION	1980	2000	2020
New England 1	0.0	0.1	0.1
North Atlantic 2	0.0	0.1	0.1
South Atlantic 3	0.2	0.5	0.8
East South Central 4	0.2	0.4	0.6
East North Central 5	0.3	0.4	0.5
West South Central 6	0.3	0.6	1.5
West North Central 7	0.4	0.8	2.2
Pacific Coast 8	0.4	0.7	1.9
Mountains 9	0.4	0.8	2.2
Total	2.2	4.4	9.9

Because biomass can be converted to gas in the same way as coal, and at about the same costs, we compared biomass resource costs to the delivered price of coal. As Figure 2-9 shows, biomass is only competitive with coal at the solar emphasis cost level of 50% reduction below our reference estimate. The feasibility of large-scale plantation growing of biomass is determined not only by the prices of competing energy sources, but also by the profits from growing valuable, normal agricultural crops and timber on the same land. For this reason, biomass based on plantation growing is not likely to be competitive; therefore, biomass is essentially limited to about 10 quads.

Of course, if synthetic gas from coal proves to cost $3.50 to $4.00, then biomass gas would be competitive. Alternatively it would require a 50% reduction in biomass costs to make biomass competitive. If such a cost reduction were achieved, then biomass could provide a significant source of energy. These tradeoffs are shown in Figure 2-10 and Table 2-8.

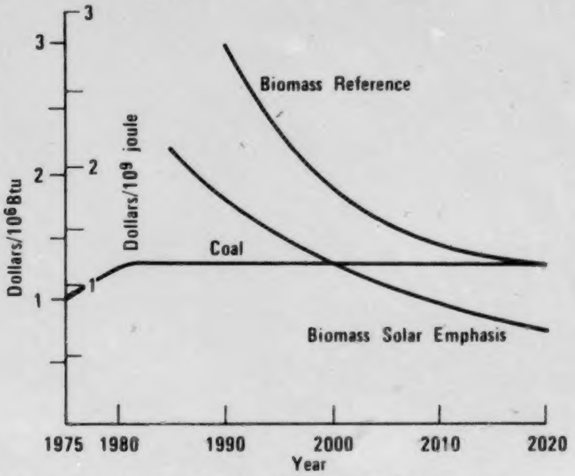
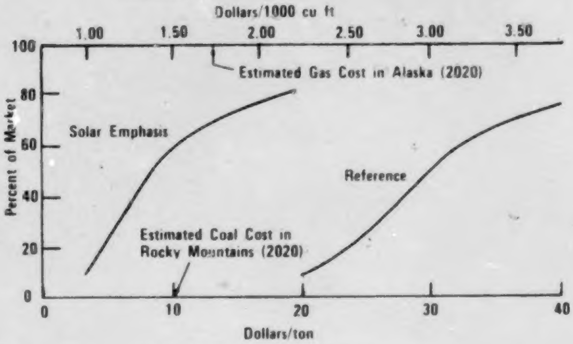


Figure 2-9 Cost of Biomass Resource and LS/LBtu Coal--Region 8 (Pacific)



Biomass Resource--$1.50/10^6 Btu (conversion efficiency; biomass to syngas -- 65%; coal to syngas -- 65%)

Figure 2-10 Solar Market Share--HBtu Gas from Biomass--Region 8 (Pacific)

TABLE 2-7

DEMAND FOR HIGH BTU GAS

	1975	1985		2000		2020	
		Low Demand	Reference & Solar Emphasis	Low Demand	Reference & Solar Emphasis	Low Demand	Reference & Solar Emphasis
Marketed Gas	18.7	18.8	19.7	21.2	21.3	16.8	34.1
Estimated Primary Energy	18.7	21	22	23	25	21	54

TABLE 2-8

SUMMARY OF CONTRIBUTION OF BIOMASS
TO HIGH BTU GAS MARKETS

Synthetic Gas Costs / Biomass Resource Cost	2.50/^{6} Btu	3.00/10^6 Btu	4.00/10^6 Btu
\$1.00/10^6 Btu	No biomass	No biomass	20 quads biomass in 2020
\$1.50 /10^6 Btu	No biomass	No biomass	5 quads biomass in 2020
\$2.50/10^6 Btu	No biomass	No biomass	No biomass

Biomass, like other solar resources, has substantially different availability and potential cost competiveness in different regions. Table 2-9 shows the estimated levels of biomass use in the nine demand regions. Biomass would be used largely where it is available from southern and midwestern agricultural residues.

TABLE 2-9

REGIONAL DISTRIBUTION OF
HIGH-BTU GAS FROM BIOMASS

REGION		*1985*		*2000*		*2020*	
		Solar	*Low*	*Solar*	*Lpw*	*Solar*	*Low*
New England	1	0.1	--	0.1	0.1	0.3	0.1
Mid-Atlantic	2	0.1	--	0.1	--	0.3	0.1
South-East	3	0.5	--	1.1	0.2	2.5	0.9
Mid-South	4	0.3	--	0.8	0.1	1.7	0.6
E. North Central	5	0.1	--	0.3	0.1	0.6	0.2
South Central	6	0.6	--	1.4	--	3.0	1.1
W. North Central	7	0.5	--	1.1	0.1	2.5	0.9
Pacific	8	0.1	--	0.1	--	0.3	0.1
Rocky Mountain	15	0.1	--	0.1	--	0.1	--
Total		2.3	0	5.0	0.6	11.2	4.0

5. Intermediate Electricity

Electrical demand is divided into base, intermediate, and peak loads. Base load demand is the maximum continuous demand, and is least expensive to provide with nuclear and fossil-fuel power stations since the plants can be operated 24 hours a day to pay off their investment costs. Intermediate load is the additional electricity used only from about 7:00 AM to 9:00 PM. Peak load occurs for a few hours in the late afternoon and/or early evening and accounts for less than 10% of demand. Intermediate load electricity is more expensive to provide with conventional or nuclear technology because costly generating plants are idle half the time. Because intermediate load generating plants are idle one half the day, the least expensive way to provide intermediate electricity has been to build less expensive gas turbines that use expensive gas or petroleum-derived fuels or to utilize older, less-efficient fossil-fueled equipment. Intermediate load electricity amounts to about 25% of electrical output. Total intermediate electricity demands are shown in Table 2-10 for the three scenarios.

TABLE 2-10

DEMAND FOR INTERMEDIATE ELECTRICITY
(in quads at equilibrium prices)

	1975	*1985*		*2000*		*2020*	
		Low Demand	*Reference & Solar*	*Low Demand*	*Reference & Solar*	*Low Demand*	*Reference & Solar*
Usable Energy	1.7	1.5	3.0	2.0	5.0	2.2	7.9
Primary Energy	5.1	4.5	9.0	5.6	14.0	5.5	19.8

Once again, synthetic high-Btu gas—the only economic source of large quantities of gas by the turn of the century—becomes solar energy's main competitor. Current estimates are that new combined-cycle gas turbines should be able to produce intermediate electricity at only $8.00 per million Btu (2.70¢/kWh). This system achieves high efficiency by first generating electricity with gas turbines and then using the hot turbine exhaust to heat a steam boiler to generate more electricity.

Because of its intermittent availability and its diffuse nature, solar energy is not naturally suited to providing base load electricity, a high quality resource that requires immediate availability. However, solar has a potential for providing intermediate load electrcity.

Although conventional power systems provide intermediate electricity at costs greater than base electricity, solar intermediate power is less expensive than solar base power. Because the sun is high enough to produce electricity only 6 to 8 hours per day, solar base systems would require 16 to 18 hours of storage, plus enough extra collectors to fill the storage system. The result is that a solar base system requires five kilowatts of capacity to provide one kilowatt all day long. Even more capacity is required to store enough electricity to get through a cloudy day. Because sunlight is naturally coincident with intermediate electric demand, less extra capacity and storage are needed. Roughly twice the peak capacity plus 6 hours storage would be sufficient for western locations.

The solar electric systems that would compete with the combined cycle plants for providing intermediate load electricity are solar thermal, photovoltaic, biomass, wind, and ocean thermal systems. The solar thermal processes are represented by the "power tower" which uses a large array of mirrors to focus sunlight on a central boiler. The steam from the boiler goes through a turbine to produce electricity. A small, 5-megawatt plant is under construction in New Mexico and a larger 10-megawatt one is being planned for California.

A report by the Aerospace Corporation demonstrated that a system of widely dispersed power towers could provide reliable power in sunny areas because storms and clouds would rarely block out more that one power tower at a time (Aerospace, 1974). Because of the need for large land areas—6,000 to 10,000 acres for a 1000- megawatt plant—and the complexity of the steering mechanisms, power tower systems are relatively expensive to build—over $1,000 per kW of installed capacity as compared with $220 for a gas turbine system.

Photovoltaic systems use solar electric cells similar to those that power satellites. Photovoltaic cells have been in use for many years, but they are extremely expensive. A photovoltaic system for intermediate use would cost $50,000 per kilowatt today. There is a good chance that solar cell costs will be reduced substantially, but the question is how much and how fast.

Biomass can be burned to produce electricity just as coal is. Biomass electricity from burning municipal refuse has real economic potential because it saves the cost of disposal as well as producing electricty—but there is not enough garbage to produce more than 10% of intermediate electric needs, and there are garbage-sorting and air pollution problems.

Since wind electric systems are so site specific in their economic characteristics, they cannot be compared to other systems or modeled as part of a generic cost estimate. They are discussed in detail in Section 2E.

Ocean Thermal Electric Conversion (OTEC) plants would use the temperature difference between warm, surface water and cold, deep water to run a turbine using ammonia or freon. OTEC plants were originally conceived of as producing electricity and being tied directly to the electric grid by underwater cables. The only good OTEC sites near the United States are off Florida in the Gulf Stream. The temperature differential is barely usable in this area, and the problems of strong currents and hurricanes are great. Alternatively, tropical OTEC plants near the equator could exploit a larger temperature differential with less hurricane and current interference. These plants would produce either liquid hydrogen or ammonia as a fuel, and this fuel could be shipped to the United States to generate electricity in fuel cells. The key assumption for this concept is 70% efficient fuel cells that are cheap—about \$165 per kilowatt (Applied Physics Lab, 1976). The problem with the concept is that even if such fuel cells are available, the least expensive fuels for them would be hydrogen or methane from coal at \$2.50 to \$4.50 per 10^6Btu—rather than hydrogen or ammonia from OTEC at \$5 to \$6 per 10^6Btu. Therefore, tropical OTEC should be assessed according to the price of the fuel it can deliver rather than according to the price of the electricity.

The comparison between different solar costs is shown in the following Table 2-11, and Figure 2-11 shows the comparison between predicted nonsolar costs and alternative levels of solar costs. Figure 2-12 shows the resulting solar market shares for different cost levels of solar electricity and its competitors. Because there is such uncertainty about the price of solar electricity, we show in Table 2-12 our solar electric cost assumptions used for the three scenarios in the study. In this way readers can compare these cost assumptions with various costs estimates from different sources that are now or will become available in the future.

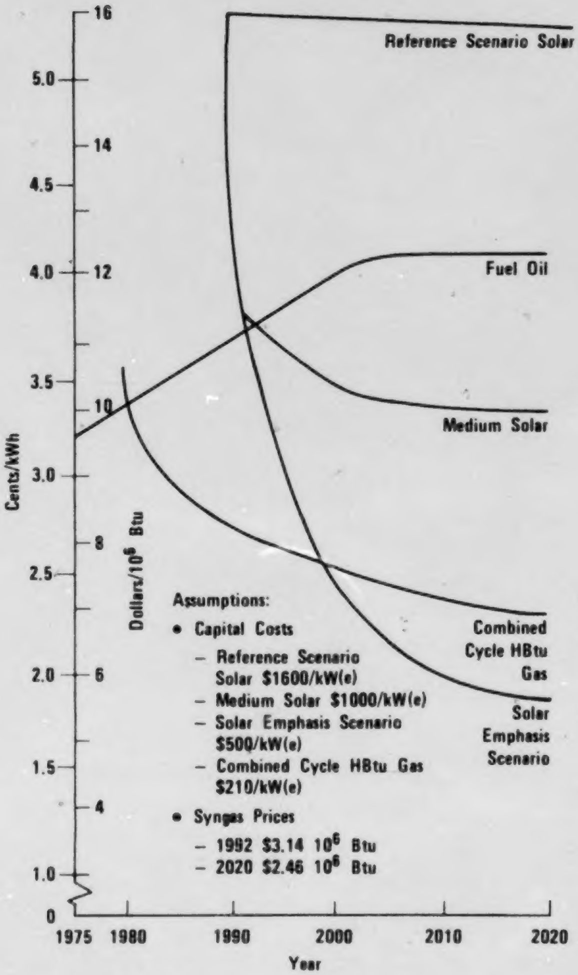


Figure 2-11 Cost of Intermediate Electricity--Region 8 (Pacific)

TABLE 2-11

COSTS OF SOLAR INTERMEDIATE ELECTRIC TECHNOLOGIES, 1990

Process	*\$/kW Capacity*	*Capacity factor*	*Effective Capital Cost*	*¢/kWh*
Photovoltaic[1]	1050-2500	0.4	2625-6250	6-12
Solar thermal[1]	1100-2200	0.4	2750-5500	6-11
Biomass[1]	520	0.4	800	4.1
Tropical OTEC plus Fuel Cells[2]	1825	0.9	2025	2.7

Source: 1. SRI, "Costs of Alternative Sources of Electricity," 1976.
2. OTEC from: "Technical and Economic Feasibility of Ocean Thermal Energy Conversion," Dugger, Francis, and Avery, Applied Physics Lab. 1976, p.27: SRI translated from base to intermediate costs.

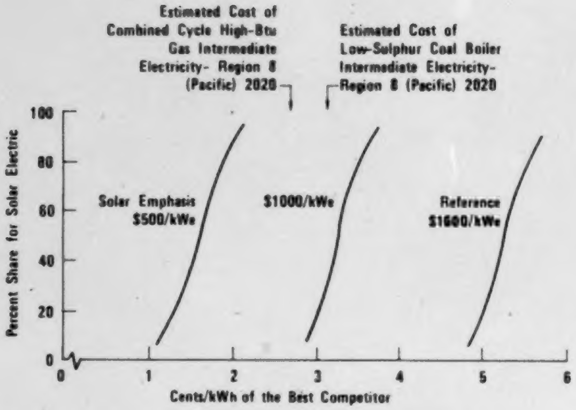


Figure 2-12 Solar Market Share--Intermediate Electricity--Region 8 (Pacific-2020)

TABLE 2-12

SOLAR ELECTRIC SOSTS FOR CALIFORNIA IN 1990

	Assumptions Used in this Study[1]		
	Reference	*Solar Emphasis*	*Low Demand*
Capital Cost $/kW(e)			
Base	2400	2400	1375
Intermediate	1600	500	950
Price of Output, in 2020, ¢/kWh			
Base	4.6	4.6	2.6
Intermediate	5.2	2.0	3.1

[1] The study uses solar electric costs generically to represent any solar intermediate load electric process. Capital costs are simulated to drop 20% from these values over time.

6. Base Electricity

Base load electricity is a large and fast growing energy demand. The total national base load demand that was assumed for these scenarios is shown in Table 2-13.

Most solar electric processes have projected costs that would not make them competitive for base load electricity, given present or projected costs for nuclear or coal-fired base electric generating stations. Photovoltaic, and solar thermal electric processes would require either major cost reductions beyond those now envisioned or substantial operating subsidies to enter the base electric market. Even if nuclear power were prohibited, coal power is less expensive than these solar base electric processes. As will be argued in the following chapter, energy conservation may be less costly in many ways than expanded nuclear, coal, or solar base electric power. Figure 2-13 shows comparative base electric costs in the area most advantageous for solar-the Southwest.

Only one solar base electric process seems to be close to competitive for base electricity. This is tropical OTEC using fuel cells. Near-shore OTEC is about twice as expensive as tropical OTEC. Even the tropical OTEC system is only close to competitive with high cost estimates for nuclear and coal as shown in Figure 2-13. Note that even if cheap and efficient fuel cells exist, the question is one of delivered fuel cost. Tropical OTEC base electricity would be competitive only if cheap fuel cells exist *and* if OTEC produced fuel could be delivered to the fuel cells for less than the cost of hydrogen or methane from coal.

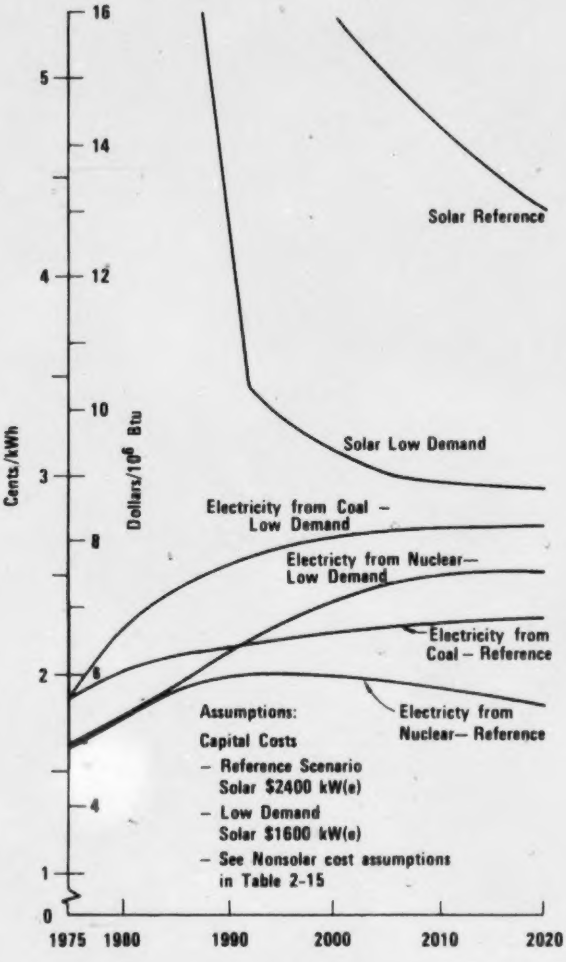


Figure 2-13 Cost of Base Electricity—Region 8 (Pacific)

TABLE 2-13

BASE LOAD ELECTRIC DEMAND

	1975	1985		2000		2020	
		Low Demand	Reference & Solar	Low Demand	Reference & Solar	Low Demand	Reference & Solar
Useable Energy	4.7	6.4	8.6	8.9	14.3	10.1	22.4
Primary Energy	14.1	19.2	25.8	26.7	42.9	30.3	67.2

Another approach could be to use OTEC electricity for direct on-board production of valuable energy-intensive materials such as aluminum or ammonia. The aluminum production alternative could be competitive with average future electric costs, but aluminum and chemical plants have located in areas where electric rates are extremely low (usually artificially). Aluminum plants, for instance, use cheap electricity from TVA, Bonneville, and other federally subsidized power systems. OTEC cannot compete successfully with these present subsidized power systems, but it could compete against unsubsidized electricity. In the case of ammonia production, the competitive situation would be more difficult because OTEC ammonia must compete with ammonia from coal. Therefore the economic competitiveness of OTEC ammonia depends on coal conversion costs.

Although solar electric processes are unlikely to be able to produce base load electricity competitively, it should not be assumed that the present mix between base and intermediate load is fixed. If the nation decided to move to solar electricity, for whatever reason, it would be reasonable to charge higher night time rates and shift electric demand back to the daytime. This could be less expensive, particularly when all the "costs" are counted, such as the interests of night time workers, than building expensive storage to force solar to provide night time electricity.

Because of all the problems inherent in solar base load electricity, we project no solar base load in any of our scenarios. This is not to say that solar base load is impossible, it just appears technically easier as well as less expensive to use solar energy for other purposes.

D. HOW TO CLOSE THE COST GAP

We have now reviewed the seven most important potential markets for solar energy. In two of these, rural heat and water heating, solar energy is likely to be cost competitive with little further federal assistance as long as direct and indirect federal subsidies to competing forms of energy—electricity and gas—are removed. However, at the reference case cost levels, we have only 11 quads of solar energy compared to the 45-quad goal of ERDA-49. This difference is due to the fact that in the reference case there is a significant cost gap between solar and competing nonsolar energy sources. We found this cost gap in residential/commercial heating, industrial heating, biomass, intermediate electricity, and base load electricity.

If we wish to reach the ERDA-49 goals, the issue becomes one of how to close the cost gap. There are three direct ways: technical progress, direct solar subsidies, and increased costs of alternative energy sources. In addition, there are several indirect means of reducing the cost gap. We discuss two of these, federal action to lower interest rates and encouragement of lifestyles more amenable to using solar energy.

1. Technical Progress

The results of R&D are impossible to predict in detail, but some general observations are possible. Solar home heating systems involving a total home redesign along with mass produced collectors and control systems could cost less than $4,000. An ordinary home roof costs several thousand dollars; therefore, factory-assembled integral solar roof units could lower cost by having functions both as a roof and as a solar system. Alternatively, more extensive use of ingenious passive systems and continued development of advanced collector systems could produce cost benefits.

In the case of intermediate load electricity, photovoltaic systems, like all other semiconductor systems, have a potential for dramatic, unexpected breakthroughs. For example, it is possible that some new invention will appear or some new technology will work. However, such breakthroughs are far from automatic. Just because transistors came down in price by a factor of

1000 or more, does not mean the same improvement can be assumed for photovoltaic cells. Both solar cells and transistors are made from expensive, ultra-pure silicon. Progress has been made in fabricating and miniaturizing transistors, but the silicon is nearly as expensive as ever. Solar cells can be made of slightly less pure and, hence, less expensive silicon. Other less expensive materials are also being developed for solar cells. Using focusing collectors might help, but cells suitable for high temperatures need further development. A focusing collector with air circulated to cool the photovoltaic cells could use the warmed air for water or space heat, thus increasing energy utilization and effectively lowering cost.

A related argument is often advanced to predict substantial cost reductions for photovoltaic systems—that of the "learning curve." A variety of products are known to have dropped dramatically and dependably in cost as the total production over time increased. However, there is reason to think the learning curve is a reasonable expectation only in the case of a very complex assembly requiring hundreds of steps. An example is the manufacturing of automobiles where thousands of steps are necessary and tens or hundreds of thousands of units are produced. In such cases, it can be reliably predicted that increased production will bring much lower per unit production costs. Photovoltaic cells, however, are not the same kind of complex assembly as an automobile. Although photovoltaic cells may drop in price as more are purchased, it is not certain that there will be dramatic price reductions.

Solar thermal power plants require about 1 square mile of land (containing about 1/2 square mile of focused and tracking collector surface) to produce 100 MW of intermediate power. This much equipment will be unavoidably costly. Major design innovations of the power-tower concept may be necessary before it can be cost-competitive. As in the case of photovoltaics, it will be difficult for mass production of presently costly systems to solve this problem.

2. Direct Subsidy

If solar cannot be made cost competitive through technical progress, direct subsidy is an alternative. Subsidies are costly and often inefficient, but they are widespread. If the existing $10 billion annual subsidies to single family homes or $2 billion subsidies to life insurance are justified, then a solar subsidy cannot be rejected out of hand (Stat. Abstract, 1975).

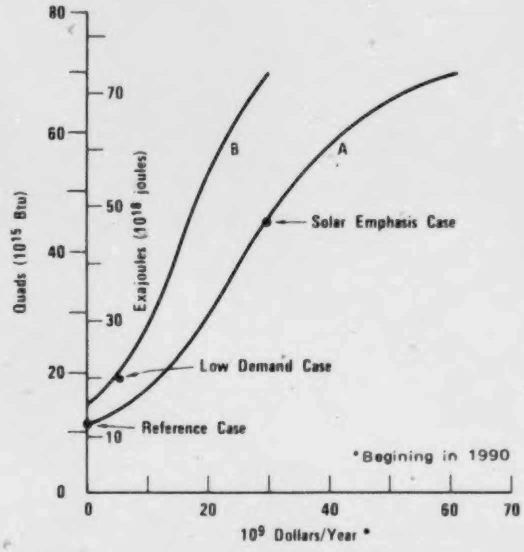
With sufficient subsidy it would be possible to reach any desired level of solar energy supply, but it is not at all simple to design an efficient subsidy system. First of all, ***any subsidy of any energy supply makes energy cheaper and to that extent it discourages conservation.*** Thus in this sense, subsidizing solar energy competes with conservation. Secondly, any uniform subsidy would redistribute income. Some group would gain at the expense of another. For example, suppose the government chose to pay one-half the cost of any solar home heating system. That would aid home owners at the expense of renters. As another example, consider subsidizing solar electricity. A subsidy just large enough to make solar electricity competititve in Minnesota would be enough to give Californians a large net profit in cheap electricity since sunlight is more available in California. Such equity issues abound in any subsidy system, but they are particularly difficult where the net benefits vary geographically. Finally, solar subsidy costs could be in the tens of billions of dollars per year.

Everyone does not uniformly bear the burden of these subsidy costs. Consumers will regain some of the subsidy in lower energy prices. This savings could amount to half or more of the cost of the subsidy. On the other hand, the owners of scarce energy resources, oil, gas, coal, and uranium lose substantial potential profits when any new competitor appears. This profit loss comes from the fact that solar or any other competitor reduces the present and future price for oil, natural gas, and other scarce resources. Resources owners still make better than "normal" profits unless they recently bought the oil or gas leases in anticipation of future price increases. Such recent purchasers show a net loss. Much of the potential profits lost by resource owners would be borne by the federal government because it owns a large share of fossil energy resources. Note that the resource owner loss depends on the level of solar energy prices and solar penetration not the level of subsidy. If the same solar level could be achieved through technical progress, resource owners would still lose.

The assumption of some general consumer savings assumes that all cost savings would be passed on to the consumer. The more likely case would be the capture of much of the consumer benefits by key workers and producers through higher wages and profits in solar and other industries.

Based upon the many assumptions we have developed in the previous pages, we estimate the following annual subsidy costs assuming no technical progress beyond that projected for the reference case; $10 billion to reach 15 quads solar, about $30 billion to reach 44 quads solar (the solar emphasis case), and $60 billion to reach 70 quads solar by 2020 (see Figure 2-14). Note that the amount of solar energy per dollar of subsidy decreases as the solar contribution increases because it becomes more difficult to reach higher levels of solar energy use. This is shown in Figure 2- 14.

Because the electric sector is so large and uncertain, we also calculated subsidy costs assuming substantially more technical progress in solar electric systems. This case is represented by the upper curve in Figure 2-14.



Assumptions:

Curve A

- Unsubsidized Intermediate Solar Electric Costs $1600/kW(e) in Region 8 (Pacific) and all other solar costs are scaled as appropriate.
- Total Energy Supply in 2020 about 200 quads.

Curve B

- Unsubsidized Intermediate Solar Electric Costs $1000/kW(e) in Region 8 (Pacific) and all other solar costs are scaled as appropriate.
- Total Energy Supply in 2020 about 200 quad.

Figure 2-14 Annual Subsidy Cost and Solar Penetration (2020)

3. Increased Nonsolar Costs

The above market penetration results depend on key estimates of nonsolar energy costs—electricity the same as 1975, and both gas and oil at about twice today's prices.

The strategy of encouraging solar through taxing or otherwise increasing nonsolar costs deserves serious consideration. If the energy problem is viewed as using too much irreplaceable fossil and nuclear resources, then a reasonable policy alternative is to increase the price of these resources. A policy of increasing the price of nuclear and fossil fuel has at least two major effects: it discourages overall energy consumption by making energy more costly, and it encourages the use of renewable energy resources such as solar. If solar is already close to the cost of the other energy sources (the likely case for heating), then raising the price of the nonsolar alternatives will bring a large shift to solar, with only modest overall reductions in energy use. If solar is much more costly than its alternatives (the more likely case for electricity), then a tax on energy resources judged less desirable will lead to reductions in energy use, with only modest increases in solar energy. If the objective is reducing consumption of irreplaceable energy sources, then whether this is accomplished through high solar energy use with few other energy conservation efforts or low solar use with high energy- conservation efforts is of lesser importance.

4. Taxes, Inflation, and Interest Rates

There is much evidence that U.S. interest rates are kept high both by a policy of high taxation of savings and capital and by present high inflation rates. Because solar energy systems are largely one- time capital expenditures, solar costs are quite sensitive to these interest rates. We have used a 15% interest rate for residential markets, 13% for industry, and 11% for electric utilities as approximations of present interest rates. Present U.S. interest rates are well above historic U.S. interest rates. These high interest rates reflect two things, inflation and income taxes. For example, if a corporate bond pays 10% interest and the average income tax rate is 33% then the after tax interest rate is only 6.7%. If inflation stays at the recent average of 6%, then the real after tax return is only 0.7%. Such low after tax, real interest rates discourage saving, while the high interest cost to the consumer discourages the use of capital-intensive products such as solar. It has been estimated that ending Federal taxation of interest and corporate profits would reduce interest rates by nearly one-half. Because solar costs are largely dependent on interest rates, a 50% reduction in interest rates would reduce the relative costs of solar energy so much that it would be economically competitive to use 20 to 30 quads of solar energy with little further solar technical progress.

Interest rates also affect nonsolar costs. Because nuclear energy is nearly as capital intensive as solar energy, reducing interest rates helps nuclear almost as much as it helps solar. In the use of fossil fuels, a low interest rate makes it more profitable to raise oil, gas, and coal prices today and save the resource for the future.

Finally, because of income taxes, a penny saved is about 1.5¢ earned (for an average middle-income family), that is, saving money by saving energy is tax-free income. Because solar interest costs are tax deductible, the income tax system encourages borrowing money to invest in solar rather than borrowing money to make some other investment such as building a factory where the benefits would be taxable.

5. Solar Lifestyles

One of the problems with solar energy is that it has been assumed that solar systems must be designed to be just as reliable and responsive as traditional energy sources. This adds large storage costs for solar systems. A modest life style change to adapt human activities to solar availability would make some of this extra cost unnecessary. If families were willing to throw on extra blankets and not do the laundry on cold, cloudy days, far less expensive energy storage would be necessary and solar systems would be cheaper. In the case of electricity, it should not be impossible for a society to use less electricity on cloudy days.

As we have stated before, the energy alternatives in this chapter assume that national energy choices are based upon economic forces alone. The psychology of consumer choices, however, is much more complicated than this. Each consumer's life style, with its unique value system, influences his or her market choices. This distinction between economically based decisions and consumer decisions can be essential to solar feasibility. Whereas it is not feasible for consumers to make direct choices between nuclear, coal, or oil, because it is not practical for an individual to own a reactor, mine, or well, it *is* feasible for a consumer to make a choice for solar, even though it is not "economic." That is to say, solar is a unique technology which moves away from the existing pattern of a class of energy producers (dominated by economics) and separated from the class of energy consumers. Solar permits the producer and consumer to be one, thereby moving consumer psychology into the energy production sector.

The impacts of this are largely unknown; however, many may be described. Some homeowners *have* spent over $10,000 for complex solar heating and cooling systems which are clearly "uneconomic" by traditional evaluation. Many other homeowners have installed "do-it-yourself" solar systems following the example of articles in ***Popular Science, Mother Earth News,*** and similar publications. Again, many of these systems might not be "economic" if personal time were counted. Many involve recycled materials which might be limited in availability. Many are unsightly (which only the inventor could love). Many might be unreliable and/or produce reduced levels of comfort (which only an experimenter would tolerate). These seem like serious limitations when weighed against the traditional ways of evaluating energy supply systems—but they can be entirely commonplace components of consumer-based decisions.

There are at least three components to these choices: personal ownership, perceived ethical issues, and special economic considerations. When one owns a system, he is likely to have a different attitude toward it than toward a contracted service from someone else. For example, we have probably all seen the favorite old car breaking down, "Quaint old Nellie acting up again." But when the phone quits working, it's "Why can't that ?*/%#! phone company make a reliable phone!" For this reason, one might accept different standards of performance from one's own solar system, thereby implicitly lowering its cost.

Many persons perceive solar energy as ethically preferred to other energy sources. For this reason, they are willing to pay more and/or tolerate lower performance. This concern might be based on environmental concerns or on an interest in preserving fossil resources for the future. Although this choice is difficult to quantify into system cost, it is nonetheless real.

Finally, there are many unknowns in the economic process of consumer choice. Consumers make noneconomic choices based on style. They also make noneconomic choices based on a desire to own. For nuclear power they have no individual choice. However, solar power can permit this choice to be made. Also, many owners may want to purchase a solar system so that they will have free energy after the purchase has been paid off.

Although it is not possible to determine "the bottom line" of all of these factors, that does not deny their existence and importance. The development of solar energy introduces a new unknown—consumer psychology—into the energy supply system. And it's an unknown that could increase solar acceptance to the bewilderment of energy economics experts.

E. ENERGY SCENARIOS

Now that we have examined the individual energy markets, and several solar processes, we must choose a limited number of sets of assumptions to build the three comparison cases or scenarios.

We have examined seven energy markets:

1. Water heating
2. Rural space heat
3. Urban Space Heat
4. Industrial and agricultural heating
5. Biomass
6. Intermediate electricity
7. Base electricity.

Fourteen solar processes and combinations were examined:

1. Solar plus gas water heating
2. Solar plus electricity water heating
3. Solar plus fuel oil water heating
4. Solar plus gas space heat
5. Solar plus electric space heat
6. Solar plus fuel oil space heat
7. Solar industrial heating
8. Biomass gas
9. Biomass methanol
10. Biomass electricity
11. Photovoltaic
12. Solar thermal electricity
13. Near-shore OTEC
14. Tropical OTEC.

These markets and processes were studied at two demand levels, with three cost levels for each solar process, two gas cost levels, and two nuclear cost levels.

There are thousands of possible combinations of these assumptions. We have chosen three sets of assumptions for further analysis. The reference case was developed as the lowest cost energy future with resource and process cost estimates as delineated in the sections that follow. The solar emphasis case is our best estimate of the least expensive way to achieve 45 quads of solar energy supply. The low demand case is an example of concerted emphasis on energy conservation.

1. Synopsis

The remainder of this chapter describes the construction of energy scenarios to support analysis of the impact of possible energy futures. No one of these scenarios is a prediction of future energy supply and use. They are intended to bracket the range of plausible energy futures. The reader may consider one or more of the scenarios wildly improbable. Each scenario, however, is a self-consistent framework within which to explore the consequences of alternative energy choices, and the difficulties associated with implementing each scenario as will be described in Chapter 3.

Each scenario is defined by a set of assumptions regarding the level of energy demand in the society and the relative costs of energy from different sources. From these assumptions, the energy scenarios are constructed with the aid of the SRI energy model (Cazalet, 1975). Each scenario includes the final energy prices, market share of each resource and process, and supply and demand by region, resulting from the basic cost and demand estimates.

We must emphasize that the entire analysis depends on these cost and resource availability estimates. We therefore present them in detail so any reader can compare our basic assumptions to his own. Anyone who is uninterested in this level of technical detail may wish to turn to Section E-4.

2. Resource and Process Cost Projections

The input data necessary to generate 50-year energy scenarios contain innumerable assumptions. Although much of the data base for the model used in this study was collected in late 1975 and early 1976, a number of factors tend to cause cost projections to change. Development of new energy processes, revised estimates of amounts of resources, and differing opinions among experts as to future costs of a particular technology cause uncertainties in future costs to be inevitable. Some of the costs of key resources and processes in the model are described in the remainder of this section. It is important to remember that although these costs are part of the data base of the model, costs are treated as variable in this study by using several sets of alternative assumptions.

a RESOURCE COST PROJECTIONS

The detailed resource cost curves are given in Table 2-14, and Figures 2-15, 2-16, 2-17, and 2-18. Figure 2-18 summarizes resource availability. The resource curves show how much of the resource is available at each cost level. Cost for domestic resources is not a direct function of time; it is a function of the cumulative amount mined or pumped. As cheap resources are consumed, only more expensive ones remain. For any given resource and technology, resource prices increase with volume used. Note that for several oil and gas regions the resource curve becomes vertical. That means that the resource is essentially exhausted because only little more oil or gas would be produced even with very large price increases. Imported oil costs, on the other hand, are assumed to be a function of time. Imported oil prices are assumed to rise to $21 per barrel by 2020 in the references and solar scenarios and to $25 per barrel in the low demand scenario. (Figure 2-19.) As with many of these assumptions, this one might not hold true, particularly in light of recent OPEC decisions.

b. PROCESS COST PROJECTIONS

Some key process cost projections are summarized in Table 2-15. Process costs change modestly with time due to learning curve effects and tighter environmental controls. Most process costs decrease, particularly solar power plants, and some costs do not change with time (e.g., home heating furnaces).

c. ENERGY PROCESSES NOT MODELED

There are a number of energy processes that are not specifically treated in the model because of economic and technical uncertainties. For example, fusion power, space satellite power, and thorium reactors are not specially modeled. To the extent that they have similar costs and performance, these more speculative electric power processes can be considered to be represented implicitly by the generic process efficiencies and costs of other advanced electric baseload power processes (such as advanced reactors and solar electric processes).

The potential of wind systems has not been modeled in this study for several reasons. While small scale uses of wind (e.g., water pumping) will undoubtably be practical, the contribution of these systems to the

TABLE 2-14

SUMMARY OF COST PROJECTIONS OF PRIMARY ENERGY RESOURCES
(Coal, Domestic Oil, Natural Gas, Oil Shale, and Uranium)

	Initial Cost	*Up to Volume*	*Intermediate Cost*	*Up to Volume*	*Peak Cost*	*Through Volume*
Coal	*($/ton)*	*(10^9 tons)*	*($/ton)*	*(10^9 tons)*	*($/ton)*	*(10^9 tons)*
Powder River	5.0	39	35.0	559	150.0	781
Southern Illinois	11.0	12	41.0	258	150.0	288
Appalachia	10.0	2	36.0	73	150.0	75
Oil	*($/bbl)*	*(Billion bbl)*	*($/bbl)*	*(Billion bbl)*	*($/bbl)*	*(Billion bbl)*
Gulf Coast	4.5	5	15.0	33	30.0	42.2
North Alaska	6.0	4	16.8	40	30.0	55.6
Gas	*($/1000 cu ft)*	*(10^{12} cu ft)*	*($/1000 cu ft)*	*(10^{12} cu ft)*	*($/1000 cu ft)*	*(10^{12} cu ft)*
Gulf Coast	0.3	50	2.0	250	5	294
North Alaska	0.55	34	3.1	136	5	170
Oil Shale	*($/bbl)*	*(Billion bbl)*	*($/bbl)*	*(Billion bbl).*	*($/bbl)*	*(Billion bbl)*
	10.0	0	13.6	188	28	1044
Uranium	*($/$10^6$ Btu)*	*(10^9/lb)*	*($/$10^6$ Btu)*	*(10^9/lb)*	*($/$10^6$ Btu)*	*(10^9/lb)*
	0.32	1.5	0.7	12	1.3	24

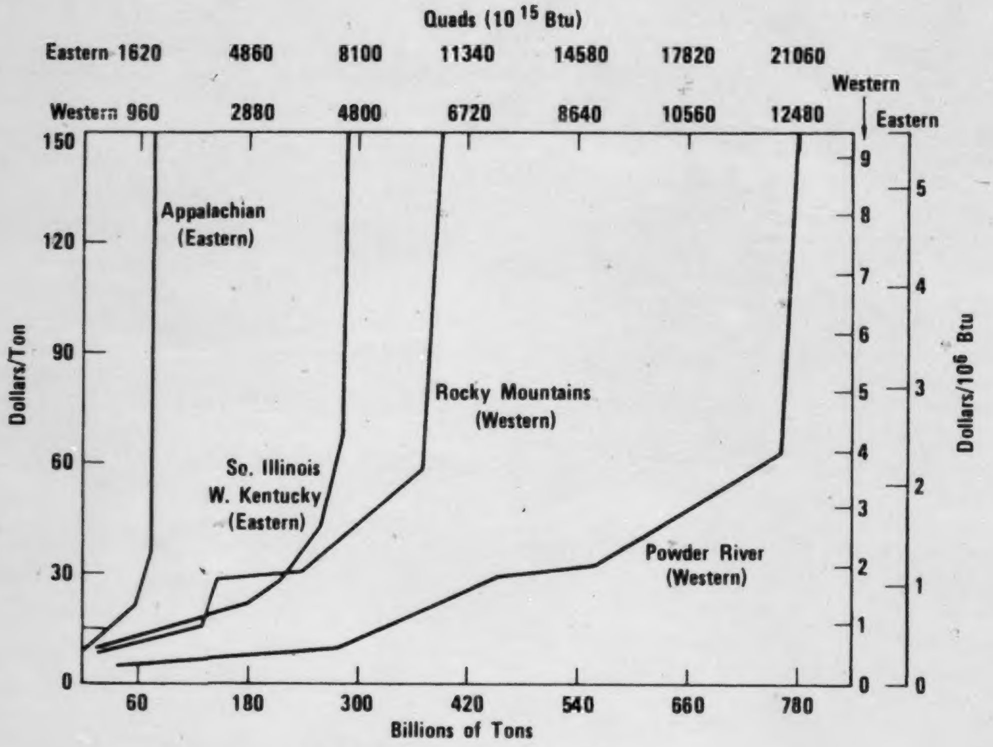


Figure 2-15 Coal Resource Curves

TABLE 2-15

COSTS OF KEY ENERGY CONVERSION PROCESSES

Reference Case

	1990			2020		
Base Electric Power	*Capital Cost $/kW(e)*	*Output Cost ¢/kWh (at plant)*	*Conversion Efficiency %*	*Capital Cost $/kW(e)*	*Output Cost ¢/kWh (at plant)*	*Conversion Efficiency %*
Nuclear						
Southwest	784	2.0	32	705	1.8	65
Coal						
Southwest	550	2.2	38	556	2.3	38
Syncrude	*$ per bbl/yr*	*$ per bbl*	*%*	*$ per bbl/yr*	*$ per bbl*	*%*
Western Coal						
Powder River	51.64	31.29	66	46.48	17.78	66
Eastern Coal						
Illinois	50.73	32.78	67	45.66	18.92	67
Oil Shale						
Rocky Mountain	11.29	33.57	9	10.16	19.38	9
Coal Gasification	*$/10⁶ Btu per year*	*$/10⁶ Btu*	*%*	*$/10⁶ Btu per year*	*$/10⁶ Btu*	*%*
Western Coal	8.55	3.72	64	7.70	2.25	64
Eastern Coal	9.50	4.28	58	8.55	2.71	58

Note:
- Electric Power capital cost includes interest during construction; 30% for nuclear, 10% for solar and coal.
- All costs are in 1975 dollars.

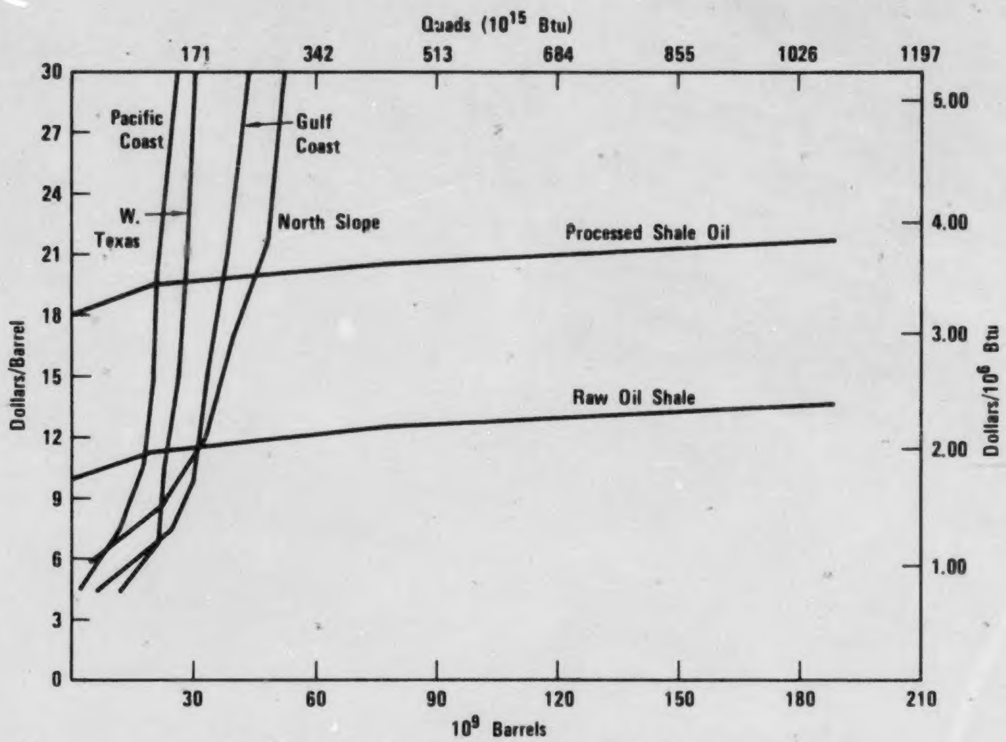


Figure 2-16 Domestic Oil Resource Curves

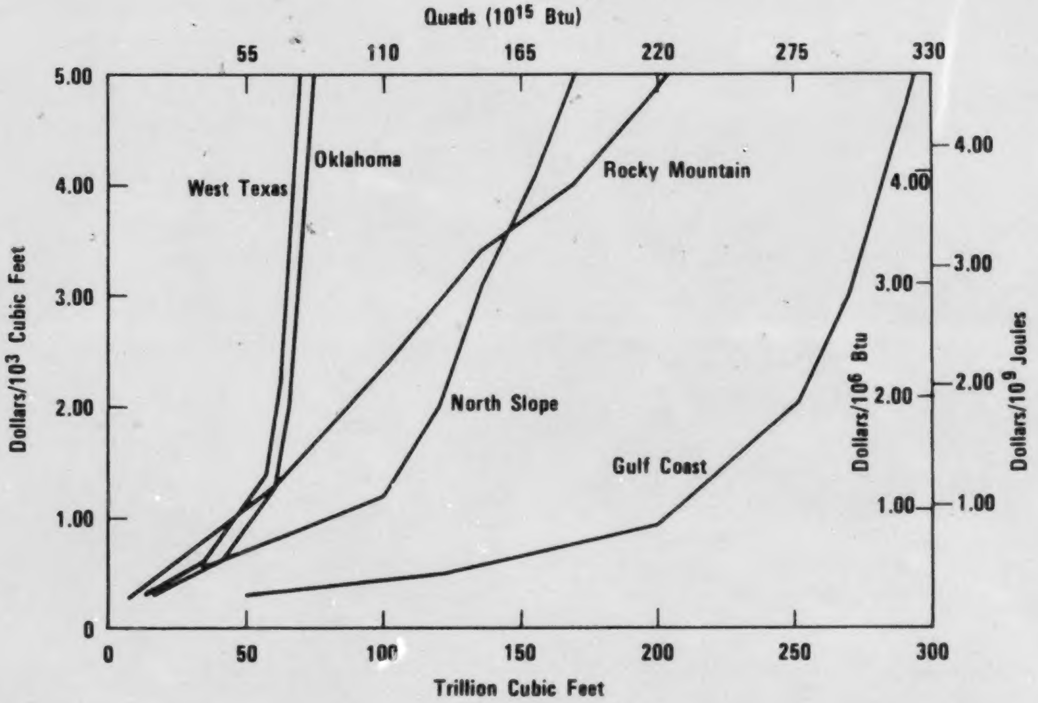


Figure 2-17 Natural Gas Resource Curves

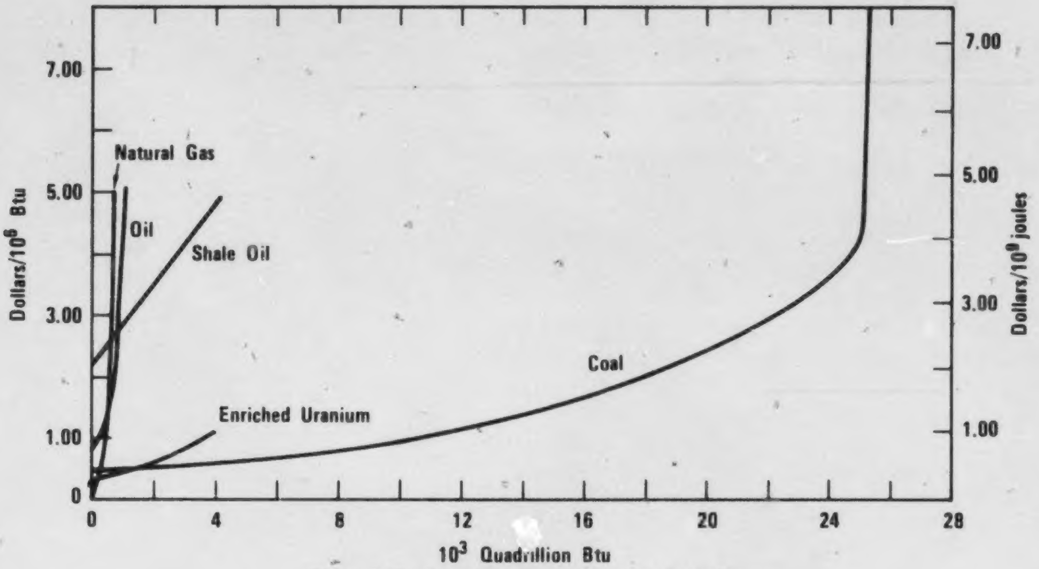


Figure 2-18 Summary—Energy Resource Availability

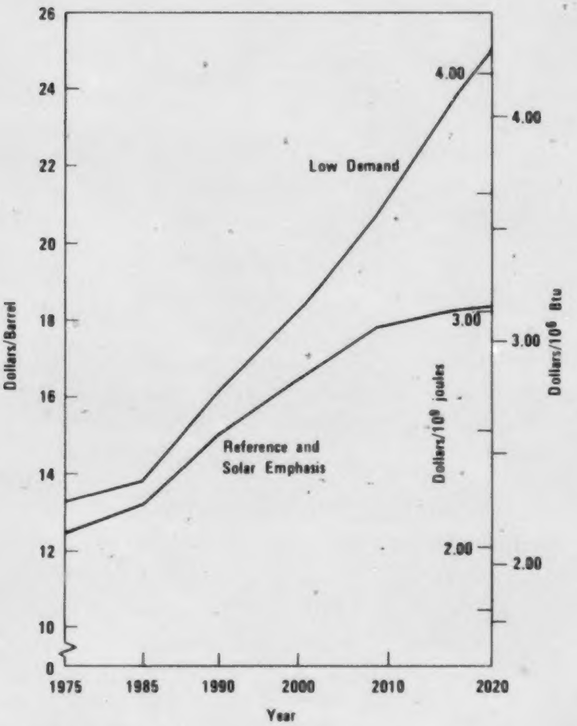


Figure 2-19 Projected Imported Oil Costs

national energy system will be small due to the small size of these demands. On the other hand, large scale uses, in which megawatt-sized wind units are integrated into larger grids, could make a sizeable contribution. For example, a recent study by Lockheed (Solar Energy Intellengence Report, 1976) showed that wind could contribute as much as 12 quads (ffe) by 1995. The potential is clearly not insignificant. However, there are several difficulties encountered in trying to verify these estimates.

Because of its variability, wind electricity is limited to being used as a fuel saver (with 100% conventional backup), as intermediate or base power where cheap storage is available, or as base power where many widespread units provide reliability. All of these alternatives are limited both by costs and by a scarcity of sites.

In the fuel saver mode, it is important that the fuel being saved is expensive; otherwise the wind units cannot be justified. Only conventional peaking and intermediate units use expensive fuel. This limits fuel saver wind systems to sites where both wind is available and large quantities of expensive intermediate electricity are used.

The combination of wind energy systems with pumped storage is limited to a few sites and often faces environmental objections. Other storage systems, such as batteries, face significant technical and economic uncertainties.

The potential for capacity displacement is also site dependent. For example, temporal, site specific wind data for several years are needed to properly locate a single wind turbine. To integrate multiple units into a single grid, the wind characteristics at many such sites would need to be statistically correlated in order to determine potential capacity displacement. Finally, concerns of system stability arise when trying to control and integrate the outputs of many, varying wind units with a single connected grid.

Wind conversion devices are currently commercially available, however their use is restricted to special sites (e.g., remote locations) due to the current high cost of from $1,000 to $2,000 per kilowatt of installed capacity. Because of variations in wind speed, the average output of a wind turbine is less than the peak capacity. Typical favorable sites will yield an average output that ranges from 40 to 60% of the peak capacity. Current research efforts are aimed at reducing the costs of both wind turbine units and wind energy storage systems. Several recent studies have shown that in mass production, wind turbines should cost as little as $500 per kilowatt of peak capacity.

It is reasonable to expect that many of these problems will be solved so that at least some wind electricity (perhaps a couple of quads) could be developed by the end of the century. And of course, even more optimistic goals could be reached. The smaller contributions of wind would displace oil, gas, and some coal. The larger contributions, providing baseload service as well, would displace some nuclear and coal.

3. Projections of Energy Use

A key parameter in any energy analysis is the estimate of energy use patterns in the future—that is, the demand for energy at a market clearing price for the energy. The energy supply for the different scenarios of the study resulting from the demand and cost assumptions are discussed in considerable detail in the next section. Energy use assumptions and the difficulties associated with reaching different levels of energy use are described first.

Energy use estimates depend on a complex relationship between energy demand and price. Normally consumers purchase less of a product as its price rises. This consumer response to price increases is weaker for energy than for most other products. This is explained by two factors: first of all, energy use is often constrained by investments in equipment that can only use one kind of energy. For example, once a homeowner buys an electric hot water heater, it would take an enormous increase in the price of electricity before it would be worthwhile to discard the electric water heater and buy a gas water heater. The second reason is that energy costs are usually a small fraction of the total cost of some larger product. When someone buys clothes, for instance, a few percent of the price of the clothes is payment for the energy used in producing the cloth, making the clothes, and transporting them to the point of sale. An energy price increase will have only a small effect on the final price of the clothes.

These facts have led some analysts to conclude that price has little or no effect on energy consumption. This may be true in the short run, but if it unlikely to be true in the long run. For example, even though some individuals may have to keep relatively expensive poorly insulated electric water heaters even if electricity prices increase, most new homes could be built with better insulated water heaters or less expensive solar water heaters. Manufacturers might also be left with equipment that uses the more expensive fuel, but as that equipment wears out, it too will be replaced with more efficient equipment that uses less expensive fuel. If all energy costs rise over a period of decades, then as both home and industrial equipment wears out and is replaced, the nation would slowly but steadily act to reduce energy consumption. This impact may be slow, but it can be very large in the long run. In our analysis we have taken into account the long run nature of these consumer responses to increases in energy prices.

Table 2-16 summarizes the end-use demand levels for energy for the scenarios. The difference between end-use demand and total energy supply is energy lost in conversion processes. In 1975, nearly 73 quads of gross energy output were necessary to meet about 45 quads of energy enduse.

a. REFERENCE AND SOLAR EMPHASIS SCENARIOS

The first set of energy end-use demands assumes economic growth averaging 3% per year, implementation of the 1985 automobile mileage standards, and annual energy growth of about 1.5% per capita or 2.5% overall. This demand projection is shown in Figure 2-20. Note that residential energy use grows slowly—largely due to slow population growth and a leveling of per capita residential energy use. The highest growth is in air transport, industrial steam, and feedstocks. As a result of the implementation of federal automobile mileage standards, automobile energy use declines through 2000, but increases again by 2020.

TABLE 2-16

ENERGY END-USE DEMAND LEVELS
[In Quads (10^{15}Btu)]

	1975	1985		2000		2020	
	Actual	Reference/ Solar	Low	Reference/ Solar	Low	Reference/ Solar	Low
Residential/Commercial (R/C)							
Space heating	3.6	4.3	4.8	5.6	4.0	7.0	4.8
Miscellaneous	2.3	3.3	2.8	4.6	2.9	6.3	2.9
Air conditioning	0.4	0.8	1.2	1.2	2.0	2.2	2.6
Electromechanical	1.1	1.8	1.4	3.1	2.2	5.9	2.8
Rural heat	1.2	1.3	1.2	1.4	1.3	1.6	1.4
Total R/C	8.6	11.5	11.4	15.9	12.4	23.0	14.5
Transportation							
Auto transportation	12.7	10.8	8.0	9.2	5.8	10.1	6.3
Truck/bus	1.5	2.4	1.4	3.6	2.0	6.3	3.2
Rail	0.6	0.9	0.9	1.5	1.0	2.5	1.2
Marine	0.6	0.9	0.9	1.3	1.0	1.9	1.2
Air transportation	2.0	3.2	2.3	6.4	2.7	10.2	3.5
Total transportation	17.4	18.2	13.5	22.0	12.5	31.0	15.4
Industrial							
Process steam	5.5	8.6	4.5	12.9	5.3	16.0	6.3
Direct heat	2.5	3.8	2.2	5.5	2.6	7.1	3.2
Electromechanical	2.0	4.0	2.3	7.5	2.8	10.0	3.4
Naptha feedstock	2.5	4.7	0.9	8.1	1.1	9.8	1.5
Gas feedstock	0.7	1.2	2.3	2.0	2.0	2.5	2.0
Coal feedstock	0.2	0.5	0.2	2.0	0.4	4.5	0.6
Miscellaneous	6.0	7.8	7.8	9.6	9.6	13.0	14.0
Total industrial	19.4	30.6	20.2	47.6	23.8	63.0	31.0
GRAND TOTAL	45.4	60.3	45.1	85.5	48.7	117.0	60.9

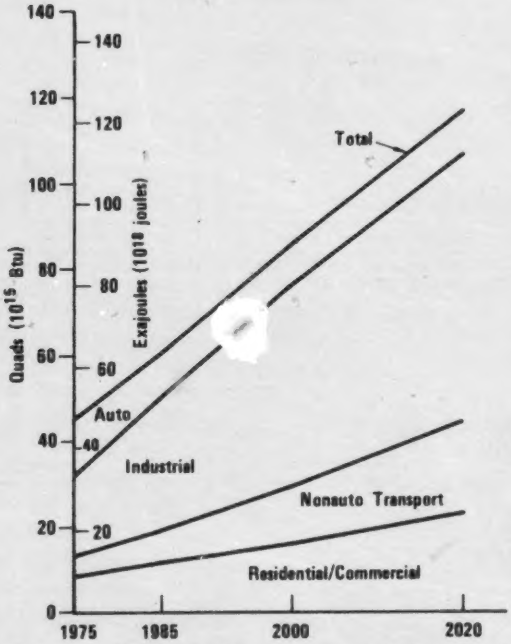


Figure 2-20 End Use Energy Demand Levels for Reference and Solar Emphasis Scenarios

b. LOW DEMAND SCENARIO

Energy use in and of itself is not intrinsically desirable. Rather, energy is a means to producing a variety of goods and services, to achieving individual and societal goals. Energy has been kept cheap in the United States, and often it has been used wastefully. But in European countries with comparable standards of living and much higher energy costs, energy utilization is far lower. (Goen & White, 1975) A recent analysis of possible U.S. response to higher energy prices concludes that there would be substantial conservation of energy in the long run if energy prices were allowed to rise, (IEA, 1977) and prices are just one of many mechanisms with which energy demand can be influenced.

The energy supply scenario corresponding to the ERDA-49 demand projection produces an estimate that real energy prices (that is, prices adjusted for general inflation) would double by 2020 in that scenario. To develop the low-demand scenario, a substantial conservation commitment by the United States is assumed—a commitment that is implemented by forcing real energy prices to double by 1985 and increase another 50% (or triple) by 2000, and remain level after 2000.

We estimated that a change in energy prices would have the following effect in the three demand sectors.

	Change in Demand When Price Doubles*
Residential/Commercial	-24%
Transportation	-22%
Industry	-21%

*In formal economic terms, we used the following elasticities:

	Income Elasticity	Price Elasticity
Residential/Commercial	1.0	-0.4
Transportation	1.0	-0.35
Industry	0.76	-0.33

We have also used a lower rate of economic growth–2% rather than 3% per year after 2000. This rate of growth is consistent with a rate of growth of the labor force that is projected to decline to 0.5% per year by 2000, and with a 1.5% per year increase in labor productivity (1970-75 average). Finally, we assume a small change in lifestyles to reduce energy use by an additional 12%.

To implement the price increase policy, the following was assumed:

Energy Source	*Cost Increase and/or Tax* *Familiar Units*	*Dollars/10⁶ Btu*
Nuclear	$0.005/kWh	1.38
Nuclear fuel	0.41/lb	--
Western coal	4.00/ton	0.25
Eastern coal	3.00/ton	0.12
Oil shale	4.50/barrel	0.75
Imported oil	5.00/barrel	0.90
Domestic oil	0.80/barrel	0.14

These increases can be thought of as either more realistic estimates of likely energy costs or as necessary taxes to be added to the costs now in the model. The increases were guesses as to amounts necessary to partially compensate for the economic costs of environmental and social problems associated with the energy sources including pollution, water use, regional growth, and saving resources for future generations. (Refer back to Table 2-16, and see Figure 2-21.)

4. Energy Supply Scenarios and Related Characteristics

The description of the results of the SRI energy model simulations is presented in this section. The purpose of this discussion is to indicate (1) the quantitative supply results that have been obtained for the different scenarios and (2) the potential contribution of solar energy in each scenario. Subsequent sections of the report will use the results presented in this section as a basis for a more complete analysis of the impacts of the scenarios and the implications of solar energy for the energy future of the United States.

These scenarios are depicted graphically in Figures 2-22 through 2-24. It may be useful to refer to Table 2-17 and these graphs during the discussions in the paragraphs below as each of the scenarios is discussed.

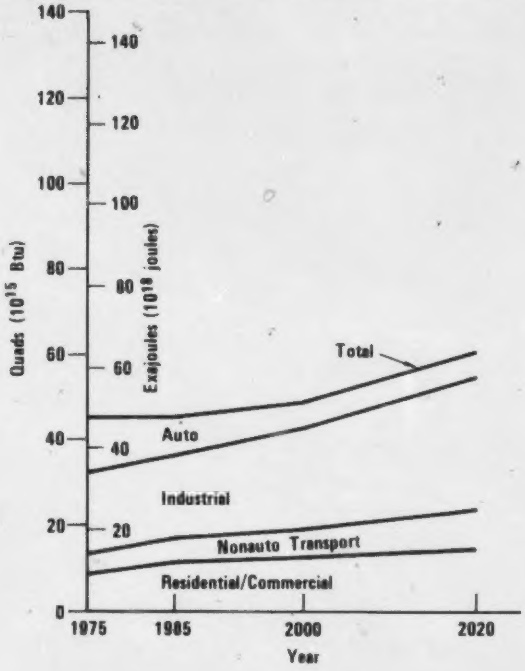


Figure 2-21 End Use Energy Demand Levels For Low Demand Scenario

a. REFERENCE CASE (198 QUADS IN 2020)

This scenario is described first because it simulates a total energy supply level close to that of ERDA-49, but with our best estimated future solar costs. It is described graphically in Figure 2-22. Note that in these graphs the top line represents the total gross energy supply curve, and the distance between the curves represents quantities of individual primary resources. The resource and cost economics assumed are as described earlier in this chapter. The most noteworthy results are:

1. Solar energy contributions to this scenario are modest, even by 2020. They include 11 quads of solar for space and water heating in 2020. Thus,

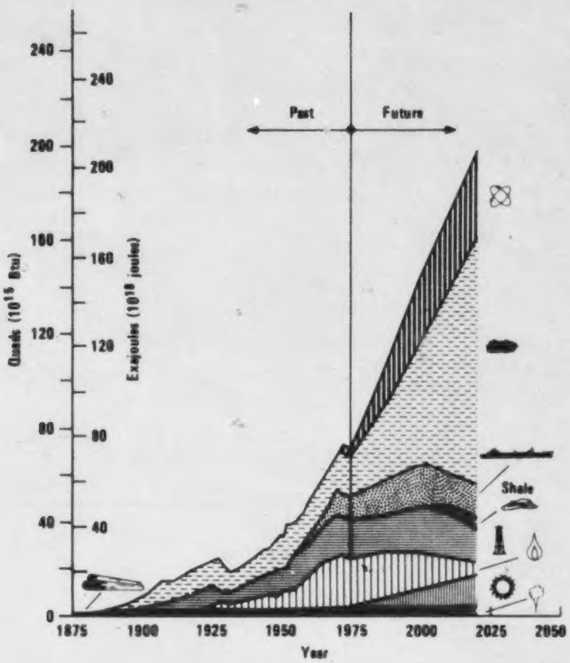


Figure 2-22 Reference Scenario Energy Supply

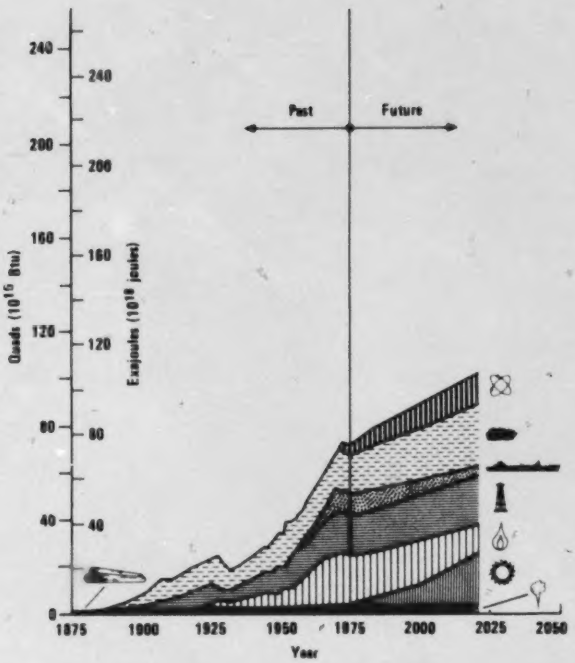


Figure 2-24 Low Demand Scenario Energy Supply

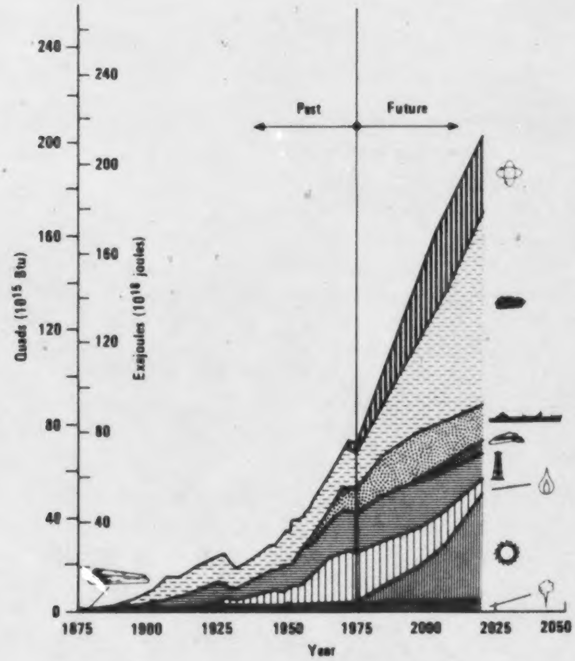


Figure 2-23 Solar Emphasis Scenario Energy Supply.

solar energy captures only about 1.5% of the market in 2000 and approximately 6% of the market in 2020. Thus, although this scenario simulates the ERDA- 49 total energy supply level, there is less solar energy. Therefore, this scenario can be thought of as simulating what would most likely happen without a major solar energy program. It emerges from detailed calculations using the resource and process cost projections of Section B.

2. Western coal production increases dramatically, from about 130 million tons per year at present to almost 4 billion tons per year by 2020. The major reasons for this rapid increase in western coal production are the relatively low resource cost of the coal, the modest cost of environmental control for coal conversion processes (due to the low sulfur content of the coal), and the economic attractiveness after the turn of the century of coal-based synthetic fuels, particularly high-Btu gas and synthetic crude oil.

3. Coal production in the East and Midwest increases rapidly, from about 500 million tons per year at present to over 1 billion tons per year in 2000 and nearly 2 billion tons per year by 2020.

TABLE 2-17

TOTAL ENERGY SUPPLY FOR THE SCENARIOS
(In quads)

		Reference			*Solar Emphasis*			*Low Demand*		
	1975	*1985*	*2000*	*2020*	*1985*	*2000*	*2020*	*1985*	*2000*	*2020*
Biomass	1	1	1	1	2	5	11	1	1	4
Solar Heating, Residential & Commercial	0	1	5	10	3	9	18	1	6	16
Solar Heating, Industrial	0	0	0	0	0	0	4	0	0	0
Solar Electricity	0	0	0	0	0	1	11	0	0	0
Total Solar	1	2	6	11	5	15	44	2	7	20
Hydro and Geothermal	3	4	4	4	4	4	4	4	4	4
Total Renewable	4	6	10	15	9	19	48	5	11	24
Nuclear	2	11	32	37	10	30	34	8	11	15
Oil Shale	0	0	1	5	0	1	6	0	0	2
Domestic Oil	19	22	21	13	21	21	11	17	18	19
Oil Imports	12	11	17	14	12	17	12	9	5	1
Gas Imports	1	2	3	2	2	2	2	1	1	2
LPG	2	2	1	1	2	1	1	2	1	1
Domestic Gas	19	20	15	6	19	15	7	20	18	12
HS/HBTU Coal	7	5	10	29	5	9	22	15	16	14
LS/LBTU Coal (Eastern)	6	3	15	15	13	14	14			
LS/LBTU Coal (Western)	2	8	21	61	6	19	47	3	9	12
Total Nonrenewable	69	93	135	183	90	129	156	74	78	78
GRAND TOTAL	73	99	145	198	99	148	204	79	89	102

4. Nuclear power increases from 2.3 quads annual resource energy at present to 32 quads in 2000 and 37 quads in 2020. This represents an increase from the equivalent of 34 one-thousand-megawatt nuclear power plants in 1975, to over 600 one-thousand-megawatt plants in 2020.

5. Natural gas production increases from 19 quads per year at present to 20 quads per year in 1985, and then declines to 15 quads per year in 2000 and 6 quads per year in 2020. The reason for the declining production of natural gas is the depletion of this resource from domestic sources.

6. Shale oil production enters the market slowly until after the 1990s. 0.2 quads are produced in 1985, 0.6 quads in 2000, and thereafter its production increases to 5 quads per year (more than 2 million barrels per day) in 2020. The rapid expansion of oil shale after the turn of the century results from rising prices of the traditional sources of liquid fuels—domestic crude production and oil imports. For both domestic crude and foreign oil, the model results suggest significant depletion of oil resources during the first and second decades of the twenty-first century.

7. Domestic crude production increases from 19 quads per year at present to 22 quads per year in 1985; thereafter it declines to below current production levels, because of the depletion (rising cost) of the resource.

8. The most significant synthetic fuels production is high-Btu coal gasification and coal liquefaction. High-Btu gasification increases quickly in the 1990s, using over one billion tons of coal per year by 2020. Coal liquefaction becomes significant in the late 1990s, and grows very rapidly thereafter, using about one billion tons of coal per year by 2020.

b. SOLAR EMPHASIS CASE (204 QUADS IN 2020)

This case uses solar heating and biomass costs 50% lower than in the reference case. Solar electric costs are 70% lower. All other assumptions are identical. The cost reductions were those necessary to produce a total solar market share approximating that in ERDA-49. The supply results are as follows (see Figure 2-23).

1. Solar energy increases to 44 quads by 2020. The largest increase from the reference scenario and

most difficult market to penetrate was intermediate electricity.

2. Solar competes almost entirely with western coal. Western coal output declines by 14 quads or not quite one billion tons per year in 2020.
3. Nuclear declines from 37 to 34 quads.
4. Eastern coal declines by 8 quads or 400 million tons per year.
5. All other energy supplies are essentially unchanged.

c. LOW DEMAND (104 QUADS IN 2020) (SEE FIGURE 2-24)

This scenario investigated two issues:

1. What would be the effect of raising nonsolar energy prices?
2. What would be the effect of a demand level of about 100 quads by 2020?

The costs of nonsolar energy sources were raised to simulate the situation wherein the reference scenario, nonsolar, energy prices might be unrealistically low and not fully include environmental and social costs associated with nuclear and fossil fuel energy production and use. The low demand case increases nonsolar energy prices to reflect some of the costs of environmental degradation, social dislocation, and depleting resources for future generations. Under the assumption that these social costs are not adequately considered in private markets, the low demand case taxes nonsolar energy sources in rough correspondence to their social costs. Taxing fossil and nuclear energy rather than directly or indirectly subsidizing solar energy has the benefit of allowing fairer—that is, nonsubsidized—choice among solar, biomass, wind, geothermal, and conservation, avoiding the difficulties of implementing any subsidy (discussed in detail in the next chapter) and avoiding the problem of discouraging conservation by subsidizing any energy source.

In Section E.3.b. we described the cost increases on nonsolar energy sources that are assumed for the scenario. Furthermore, two new, low-cost exotic technologies—high-temperature gas reactors and combined-cycle power plants were assumed not to have been successfully developed. Once again this is not a prediction but simply an examination of the consequences of what might happen if these technologies are not commercially successful.

In addition to the above cost increases, all fossil fuel resources were priced on the basis of a 3% real (corrected for inflation) discount rate (interest rate) compared to 7% in the other two cases. This discount rate is used in a "scarcity rent" calculation. Scarcity rent is a basic concept of natural resource economics explained in Section B wherein present prices are expected to be higher. For the low demand case, we reduce the average discount rate, adjusted for general inflation, from 7% to 3%. As an example of the impact of such a change, assume that 1987 oil is likely to sell at $20/barrel. With a 7% discount rate, oil should be sold today only if its price is above

$$\frac{\$20}{(1.07)^{10}} \quad \text{or} \quad \$10.17/\text{barrel}$$

At a 3% discount rate, today's minimum price should be

$$\frac{\$20}{(1.03)^{10}} \quad \text{or} \quad \$14.88/\text{barrel}$$

Scarcity rent is the primary economic mechanism for allocating limited resources between present and future generations. By raising prices today, it discourages consumption and saves resources for the future. The discount rate is a key factor in this calculation because a high-discount rate places a low value on the future. The low demand case uses a discount rate 4 percentage points lower than the other scenarios, and therefore places higher value on conserving resources for the future.

In addition, solar costs in the low demand case were assumed to be 25% below the reference case.

The results of this scenario are as follows:

1. Solar energy and biomass total 20 quads by 2020.
2. Domestic crude and gas are saved for the future with about 15% less cumulative production between 1975 and 2000.
3. Western coal production is reduced by one-half from over three billion tons per year in the reference case to about 750 million tons per year by 2020 in the low demand case.
4. Eastern high-sulfur coal production is reduced from the reference case by more than 60%; this represents essentially no growth in eastern coal production.

5. Nuclear energy in 2020 is reduced to about the number of plants now under construction or in some stage of planning.

Figure 2-25 shows the resulting cost of gasoline in the three scenarios. Figure 2-26 shows the resulting cost of electricity in the three scenarios. Note that in both cases the introduction of low-cost solar energy would not affect the costs of these two energy supplies.

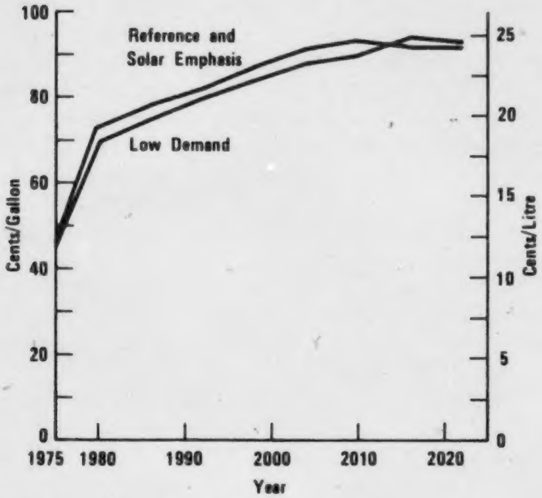


Figure 2-25 Cost of Gasoline in Each Scenario

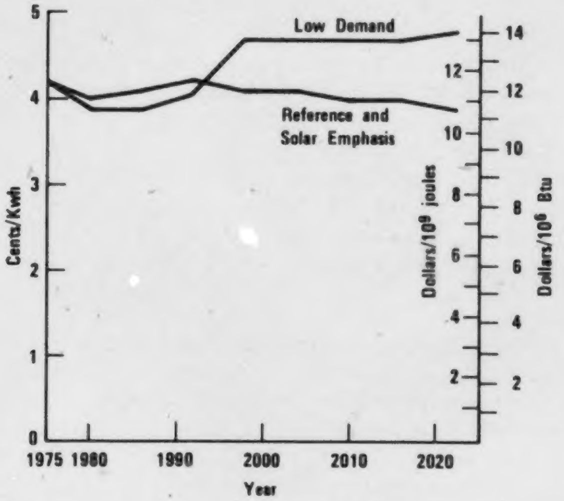


Figure 2-26 Cost of Electricity in Each Scenario

3. IMPACTS AND IMPLICATIONS OF THE SCENARIOS

The previous chapter developed sets of assumptions necessary to establish three scenarios—the reference, solar emphasis, and low demand cases—for analysis. The objective of this chapter is to understand the impacts and implications of the scenarios. If the nation is to make energy policy choices consonant with overall national goals and priorities, the attempt to understand implications of alternative energy futures is an important one.

The difficult problem is: how does one in fact evaluate the future impacts of energy scenarios? There is not a straightforward or precise way to approach this problem. One method considered for use in this study was to develop a flow from (1) relatively well-defined direct impacts of the energy process in the scenarios to (2) the implications of these impacts on affected parties to (3) the various policy measures to implement the scenario and mitigate the adverse impacts, and finally to (4) an analysis of the expected responses of stakeholder groups to the impacts and related policy implementation measures.

Although this approach seems to be highly reasonable in theory, its application can produce such complexity that the meaning of the results is very difficult to integrate. This can be understood by considering the environmental impacts of any of the scenarios. Each scenario has at least ten different energy resources (counting, for example, western and eastern coal as different because the environmental impacts of their use are significantly different) feeding into hundreds of energy processes and used in hundreds or thousands of different ways. The overall environmental impact depends not only on these energy processes but, in many cases, on the location at which the resource is extracted, converted, and used and the effectiveness of environmental control methods. For each of the combinations of resources, conversion processes, methods of transport, energy uses, locations, and environmental control methods, there are environmental impacts on air, land, and water. Tracing the impacts through the four steps of the approach yields literally millions of variables that need to be traced.

An alternative approach that is often used is to choose a surrogate for impacts that aggregates environmental impacts in some meaningful way. The most common choice is residuals (i.e., the sum of all emissions to the environment from the energy processes) or an indicator of environmental quality that is some combination of residuals and other factors that provide a measure of environmental impact. The difficulty with this approach is that it is an abstraction that is removed from the real environmental problem. This approach does not serve our purpose well because it obscures many of the policy issues that result from the specific impacts. However, in some cases it is a useful tool to distinguish impacts among different scenarios.

Our final choice more nearly resembles the four step procedure than the indicator approach. No attempt was made to be comprehensive, either in dealing with all impacts or in applying all four stages of the analysis. Rather, impacts and implications of the scenarios were addressed when they were judged to raise key issues that underlie the scenario. Thus, for the reference case scenario, implementation measures to mitigate adverse environmental impacts or to achieve the scenarios were singled out as a critical issue in the scenario assessment. For the low demand case, substantial emphasis was placed on the economic and social impacts of reduced energy growth and measures to deal with these impacts. For the solar emphasis case, specific aspects of environmental issues (especially land use and emissions to the air from the production of materials for solar energy systems) and economic measures to implement the scenarios were judged to be of greatest importance. Also the issue of the feasibility of the solar emphasis case is extremely important; this has been addressed in Chapter 2 and is reviewed in this chapter.

Thus, the approach can be summarized as emphasizing issues judged to characterize the scenarios and that reveal the most important problems and choices among them.

A. ENVIRONMENTAL IMPLICATIONS OF THE SCENARIOS

1. Overview

To achieve the reference case scenario, society must exert enormous efforts, entailing substantial conflict over the resolution of environmental issues. In 2020, the reference case has more than 600 nuclear power plants of 1000 MW(e) capacity. If the power plants are sited to minimize the cost of delivered electricity to the consumer, as assumed in the model runs, then they will be located near the largest population centers. Thus, the issue of nuclear safety is an important one in the reference case.

The most dramatic result of the reference case is the extraordinary development of regions of the American West for energy resources. Not only are almost 4 billion tons of coal mined in the West annually in 2020 (compared to 650 million annual tons today in the entire nation), but coal conversion plants abound. The reference case has 200 coal gasification plants in the Northern Great Plains (Montana, Wyoming, and North Dakota) in 2020. Each of these plants delivers 250 million standard cubic feet of gas per day, enough to heat about one million residences daily. The same area has 150 plants producing 50,000 barrels per day of crude oil from coal in 2020. The daily output of one of these coal liquefaction plants is about equal to that of one gasification plant in energy value. The reference case also has 50 plants producing oil from oil shale in 2020, each with 50,000 barrels per day output. These plants are located in the Rocky Mountain region of the U.S., primarily in the Piceance Basin of Colorado.

Such a massive development of western energy resources, as well as energy conversion on-site, may strain one's credibility, but it is the result of a decision making process based mainly on economic considerations. As we will note, this intensity of energy development raises serious environmental issues concerning social impacts in the area of resource development, the lack of water and the need to import it (presumably through interbasin transfers), the maintenance of air quality standards, protection of wilderness areas, preservation of the integrity of the land, etc.

Having isolated nuclear power and western energy development as the two critical environmental issues of the reference case, we wish to know the extent to which the solar emphasis case provides a vehicle for avoiding these problems. The answer is that it reduces the impacts only in limited measure. The solar emphasis case has 580 nuclear power plants (versus 630 in the reference case) in 2020. 170 synthetic crude oil plants are sited in the Great Plains in 2020 in the solar emphasis case, 20 more than in the reference case. The solar emphasis case has 130 gasification plants in the same region in 2020. This is 70 fewer than in the reference case. And there are 60 oil shale plants in the solar emphasis case, 10 more than in the reference case in 2020. Thus, although the solar emphasis case does provide some relief from the major environmental problems in the reference case, this relief is limited in nature and extent.

The low demand case explores one route to achieve reduced environmental impacts. This scenario has 3 coal gasifiaction plants, 20 coal liquefaction plants, and 20 oil shale plants in the West in 2020. The low demand case has 255 nuclear power plants in 2020, under the assumption that nuclear power is judged socially acceptable. If nuclear power is not accepted, then there is ample supply flexibility to select other resources (particularly eastern coal) to provide electricity. Thus, although the low demand case does not avoid all environmental problems, it appears to point to the fundamental direction society would need to move if it is to avoid the environmental impacts of the higher demand cases.

2. The Reference Case

As noted, many of the critical issues of the reference case concern environmental impacts. To best focus attention on the interplay of these impacts with laws, regulations, institutions of society, attitudes, interest group reactions, conflicts and similar nonquantifiable but pertinent aspects of the reference case, the discussion focuses on a set of plausible implementation measures. These implementation measures have to do with mitigating adverse environmental impacts, with acquiring necessary land and water, with facilitating construction of facilities, etc. They or similar measures are required to permit the scenario to happen. We are not making the case that the measures are or are not desirable, but rather that they or related measures serve as a guide to understanding the implications of the reference case. Later, in the discussion of stakeholder response to the scenarios, an effort is devoted to assessing the social impacts of and responses to these implementation measures.

a. NUCLEAR IMPLEMENTATION MEASURES

Figure 3-1 presents the major implementation measures needed to bring about the nuclear energy component of the reference case. The growth of nuclear power is particularly rapid in the late 1970s and 1980s in the reference case. Between now and 1985, approximately 200 new one-thousand-megawatt nuclear power plants would have to be sited, constructed, and delivering power.* Because nuclear power plants presently require at least seven years for siting and construction, and often longer, this level of growth in nuclear power implies:

- A significant improvement in the capital market for utilities in the near term.
- A determination by a large number of public utilities commissions that there is a legitimate need for additional generating capacity, approximately doubling current capacity over the next ten years.

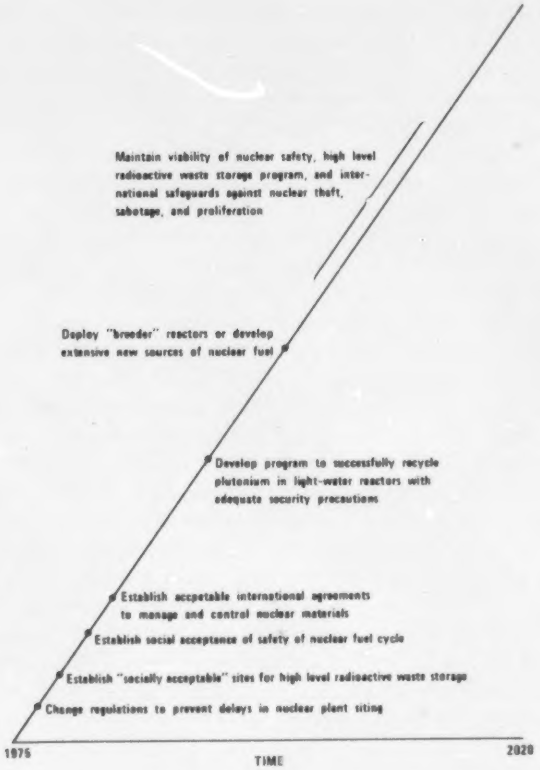

Maintain viability of nuclear safety, high level radioactive waste storage program, and international safeguards against nuclear theft, sabotage, and proliferation
Deploy "breeder" reactors or develop extensive new sources of nuclear fuel
Develop program to successfully recycle plutonium in light-water reactors with adequate security precautions
Establish acceptable international agreements to manage and control nuclear materials
Establish social acceptance of safety of nuclear fuel cycle
Establish "socially acceptable" sites for high level radioactive waste storage
Change regulations to prevent delays in nuclear plant siting
1975
TIME
2020

Figure 3-1 Nuclear Implementation Measures for Reference Case

- General public acceptance of nuclear power permitting the institution of new siting and regulatory procedures to streamline the regulatory process, thus reducing construction time for nuclear power plants.
- A societal determination that the high level radioactive waste storage problem will be amenable to solution in time to contain the wastes from the new nuclear plants (i.e., before 1985).

If the reference case is to happen, the four steps necessary to bring about the nuclear scenario must occur in the near future. This means such obstacles as the recent proposals for nuclear moratoria would have to be solidly resisted. Furthermore, because a sizeable segment of the population is currently troubled by one or more aspects of nuclear power growth, the steps necessary to permit the rapid expansion of nuclear power will probably have to be imposed over significant opposition of a minority of the American people.

The continued growth of nuclear power through the end of the century and beyond necessitates at least four additional major implementation measures; as shown in Figure 3-1: (1) the social acceptance of the safety of nuclear power plants, reprocessing facilities, and the transport of nuclear fuels, (2) the establishment of acceptable international agreements to manage and control nuclear materials, (3) the development of programs to effectively recycle plutonium for use in light-water reactors, and (4) the successful deployment of commercial breeder reactors or the discovery of vast new sources of uranium.* There is a legitimate question as to whether *any* of these measures can be successfully attained in the time frame required by the scenario. A failure to implement these measures will reduce nuclear growth.

The distribution of costs and benefits from the nuclear implementation measures is critically dependent on the degree of success attained for each of the measures. For example, if the perceived need for nuclear power permits the establishment of a weak international agreement to control the exchange of plutonium that cannot be effectively enforced and is likely to be violated, then the measure will increase the instability of the world political situation by permitting (if not encouraging) the proliferation of nuclear weapons. The point of this illustration is that social concern about the spread of nuclear materials may very well lead to international agreements, but the existence of agreements in no way guarantees that the problem of nuclear proliferation is contained.

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*The reference case has 11 quads of nuclear energy (fossil fuel equivalent) in 1985. About 17 one thousand MW(e) power plants with a conventional efficiency of 32% are needed to produce one annual quad (ffe).

*There is some uncertainty regarding the time frame in which breeder reactors are required in the reference case, with estimates ranging between 1990 and 2020. The need for a breeder in the reference case depends on (1) the extent of new discoveries of uranium, (2) the success of plutonium recycle in light-water reactors, and (3) the success of advanced nonbreeder reactors (e.g., the high temperature gas cooled reactor) that have an improved efficiency in producing electricity from uranium compared with current light-water reactors.

b. FOSSIL FUEL IMPLEMENTATION MEASURES

Fossil fuel production in the reference case in 2020 is very much larger than present levels: western coal is thirty times current western coal production levels, oil shale production is sufficient to reduce current oil import levels by almost half, and eastern coal production increases to three and one-half times current production levels. To achieve this increased energy production, significant policy decisions and major implementation measures must be effected between now and 2020. To understand what these measures are, we first ask what must be done to make possible the production of western coal at the levels of this scenario? In answer to this question, the assumptions are made that (1) the states of Wyoming and Montana do not choose or are not permitted to limit the production of coal and (2) the U.S. economy is able to function to make available sufficient capital, labor, and material resources so as to provide ample support for these mining activities (either with or without explicit governmental incentives). In the absence of the fulfillment of these two assumptions, the reference case cannot happen.

If these two assumptions hold, there remain substantial difficulties in achieving the western coal production levels of the reference scenario. By the year 2000, more than 200 coal mines in the West would produce an annual average of five million tons of coal each. By 2020, this number of coal mines will triple in the reference case. The coal must either be converted to liquid, gas, or electricity at the mine mouth in the West or transported to energy-conversion centers. Conversion of the coal in the West will require large amounts of water in regions that have limited water supplies, as well as large migration of energy company employees, their families, construction workers, and support personnel to provide basic services for the incoming population. Eventually, as the coal in the best seams becomes depleted, additional coal lands in the private or public domain will have to be made available.

In the reference scenario over one-fourth of the energy, 60 quads, comes from one small part of the Great Plains, the Northeast Wyoming, Southeast Montana, and Western North Dakota coal mining area. Because shipping the coal itself is relatively expensive, most of the energy must be converted into more easily transported gas, electricity, and syncrude. A completely new pipeline, rail, and electric transmission system must be built with new rights of way and capacity exceeding the entire present capacity of U.S. pipelines and long distance powerlines. The largest part of this system must be built in the Great Plains and Upper Midwest. Even with these pipelines and electric transmission systems, over 110 unit trains (of one hundred car length) would be needed daily heading East. This requires at least one new double-track railroad from Wyoming to roughly the Iowa-Nebraska border. Over one hundred unit trains a day each way is one train every 6 minutes. The new main line would have to be grade separated its entire length because it would be nearly impossible to cross the mainline at grade.

Similar difficulties are attendant on the shale oil production levels of the reference case. A particular problem is the inability of the Colorado River Basin to support shale oil production and at the same time meet projected increasing demands for nonenergy uses of water. This means that large quantities of water will probably have to be imported into the Colorado River Basin. Because the shale cannot be transported economically out of the Colorado River Basin area for retorting and upgrading, the most severe impacts of the development (water consumption, solid waste, rapid population growth) will be felt in the Rocky Mountain region of Colorado and Utah, where the shale oil occurs in place. ***In-situ*** processes for producing shale oil, in which the oil is essentially retorted in an underground cavity, could serve to mitigate many of these impacts, if they are commercialized.

Although it is possible that some of the activities described in the preceding paragraphs will happen through the operation of free market forces, most of them will not happen in the absence of specific federal government intervention either to remove the barriers imposed by existing laws and regulations or to initiate actions to facilitate the required production levels. There is a wide range of implementation measures that are likely to be required to facilitate or make possible the levels of western coal and oil shale production in the reference case, as well as implementation measures for the other scenarios. Figure 3-2 summarizes 13 of the more significant of these measures for the reference case.

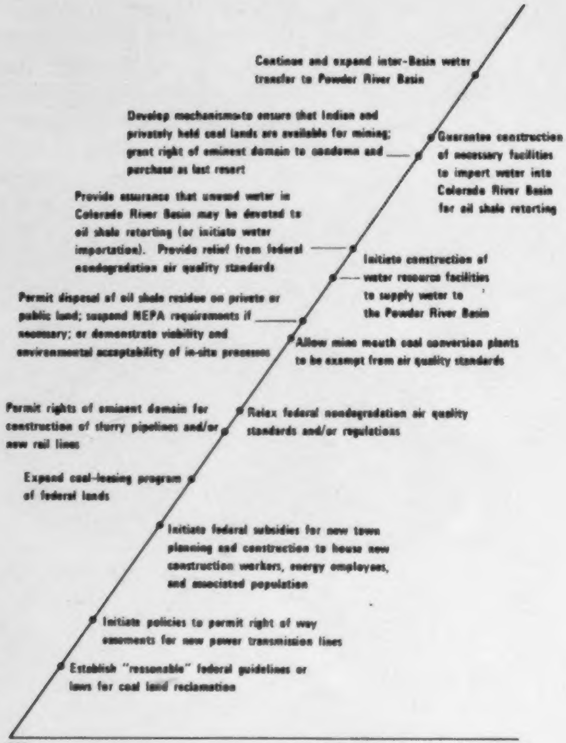
Continue and expand inter-Basin water transfer to Powder River Basin
Develop mechanisms to ensure that Indian and privately held coal lands are available for mining; grant right of eminent domain to condemn and purchase as last resort
Guarantee construction of necessary facilities to import water into Colorado River Basin for oil shale retorting
Provide assurance that unused water in Colorado River Basin may be devoted to oil shale retorting (or initiate water importation). Provide relief from federal nondegradation air quality standards
Initiate construction of water resource facilities to supply water to the Powder River Basin
Permit disposal of oil shale residue on private or public land; suspend NEPA requirements if necessary; or demonstrate viability and environmental acceptability of in-situ processes
Allow mine mouth coal conversion plants to be exempt from air quality standards
Permit rights of eminent domain for construction of slurry pipelines and/or new rail lines
Relax federal nondegradation air quality standards and/or regulations
Expand coal-leasing program of federal lands
Initiate federal subsidies for new town planning and construction to house new construction workers, energy employees, and associated population
Initiate policies to permit right of way easements for new power transmission lines
Establish "reasonable" federal guidelines or laws for coal land reclamation
1975
TIME
2020

Figure 3-2 Fossil Fuel Implementation Measures for Reference Case

To illustrate the need for these measures and some of their implications, several of the implementation measures in Figure 3-2 are discussed.

(1) Coal Land Reclamation

Without acceptable standards for reclamation of coal mined land, increasing opposition to and delays in the expansion of coal mining may be anticipated. New problems concerning reclamation have arisen as a result of the projected rapid growth in the production of western coal, because of the aridity of the land and the fragility of the ecosystem (National Academy of Sciences, 1974). The debates in Congress during the past several years over reclamation standards for surface mining illustrate the difficulty in achieving a generally acceptable definition of reclamation standards. However, the major conflicts are likely to arise from the need to achieve equitable enforcement of the standards.

(2) New-Town Planning

To avoid strong opposition by the inhabitants of the western coal regions to potentially disastrous "boom town" development, it is useful to assume that the federal government, in coordination with state and local governments and the energy industry, will develop a program to finance the front end costs of new towns and expansion of existing towns in the face of rapidly expanding populations (Gilmore, 1975). It is difficult to estimate the extent of the required financing or the source of funds or the problem of establishing institutions to plan for rapid population growth. However, extraordinary measures to reduce potentially adverse social impacts in coal-development areas appear to be required before coal development and conversion facilities "take off" to avoid extreme opposition to western coal development among influential political groups.

A fundamental issue is whether money alone can adequately deal with the problem of social change resulting from rapid population growth in sparsely populated areas. With its large component of mine-mouth energy conversion plants, the reference case has a projected population increase of one and one-half million people into the Powder River Basin by 2020. This figure includes estimates of workers in the energy industries, their families, and support population as well as the population induced into the area by new industries attracted by inexpensive energy. The present population of the Powder River Basin is under 100,000. It is difficult to envisage such a transformation without major conflict with the present inhabitants of the region as well as others interested in the protection of undeveloped areas of the United States.

(3) Air Quality Standards.

Unless unexpected technical improvements in pollution-abatement methods reduce emissions of pollutants from energy-conversion faciltiies to very low levels, the mine-mouth facilities constructed in the West are likely to violate nondegradation standards for air quality (i.e., they will produce "significant deterioration" of air that was hitherto essentially unpolluted). Even if the regulations allow the air quality region in which the plant is located to be degraded, the rapid growth of energy facilities will cause degradation of nearby air quality regions including several National Forests, National Monuments, and National Parks.

To permit the construction of increasing numbers of coal conversion facilities, present and proposed nondegradation air quality standards will undoubtably need to be relaxed. A recent analysis of the proposed legislation in the Senate on nondeterioration of air quality (U.S. Environmental Protection Agency, 1975) suggests that coal gasification plants will have to be located 7 to 40 miles away from wilderness and other Class I (no significant deterioration) areas and 0 to 6 miles from each other. Thus, although individual plants can be sited under proposed regulations, siting a large number of them (200 gasification plants in the West in the reference case in 2020) will assuredly come into conflict with air quality regulations to protect wilderness and pristine areas.

Consideration of the list of implementation measures for the reference case presented in Figure 3-2 thus permits a sense of the conflicts that may be expected to arise on environmental matters under the conditions of this scenario.

3. The Solar Emphasis Case

A selected set of implementation steps for the reference case revealed a great deal about the environmental implications of this scenario. In most cases, solar energy applications have lesser environmental impacts than the fossil energy source it replaces. Thus, in comparing the two scenarios, we concern ourselves with the impacts of the solar technologies and with the reduction in impacts from those processes that solar energy is expected to replace.

a. BIOMASS

The solar emphasis case has approximately 11 quads of energy from biomass in 2020, representing about 25% of the contribution of solar energy in the scenario. To understand the environmental impacts of using biomass, we distinguish three different sources: (1) municipal waste, (2) agricultural and forest residues, and (3) energy plantations. These are treated separately.

(1) Municipal Waste

The U.S. Environmental Protection Agency has supported efforts to use municipal waste as fuel. The experiments to date suggest the feasibility of using wastes for 10% to 20% of the fuel supply in conventional boilers of power plants. Design changes in future power systems could increase the percentage of waste as fuel.

Before firing, the municipal waste is sent to a processing plant, where it is ground up and separated into combustible and noncombustible fractions.

Specific environmental problems include virus and bacterial particles adhering to the dust emissions from the processing plant, increases in water effluents at the processing plant, and interference with the operation of the electrostatic precipitator at the power plant. The U.S. Environmental Protection Agency is actively researching these problems and expectations are that they can be managed by adopting or modifying state-of-the-art control technology (Kilgroe, Shannon, and Gorman, 1975). Because municipal waste competes with coal (in the reference case), a major benefit of its use as fuel is a reduction in coal mining impacts. The disposal problems of municipal wastes are significantly diminished if they are used as fuel.

(2) Agricultural Residues

Analysis to date on the use of agricultural residues indicates that this is a promising energy source that should yield environmental benefits. The pyrolysis of manure, barley/cotton wastes, and rice wastes to produce gas show low levels of air emissions, particularly NO_x and SO_2 (Gikis and Jones, 1976). Similar results undoubtedly obtain for the use of forest residues as a fuel source.

Advanced systems incorporate water recycle, which greatly enhances net energy output and reduces demands on water supply. Disposal of solid waste is facilitated by evaporation ponds, which, however, constitute an environmental impact that may be objectionable. Preliminary analysis indicates that the levels of pesticides and herbicides in the residues is not great enough to represent a significant environmental concern (Gikis and Jones, 1977).

Agricultural residues can also be burned directly as boiler fuel in the generation of electricity. In either use—pyrolosis to produce gas or direct burning to produce electricity—agricultural residues should result in net environmental benefits compared with the use of fossil energy: (1) reduction in agricultural waste problems, (2) reduced levels of air emissions compared to the fossil fuel alternative, (3) reduced mining of coal, and (4) reduced demand on scarce water supplies in many cases.

The fourth point requires some amplification. Tracing the energy sources with which agricultural residues compete in the reference case reveals that it generally substitutes for coal gasification. Because the coal gasification is expected to occur near resource regions, much of the gas for western markets will be produced in the Powder River Basin (northeastern Wyoming and southeastern Montana). Large gasification plants will cause a severe strain on existing sources of water supply in the region. Because the pyrolysis of agricultural residues permits much greater flexibility in siting, water availability problems should be much reduced for this option.

(3) Energy Plantations

A comparison between the land required for the raising of crops from which energy is produced and the land devoted to mining coal reveals that energy plantations need very large land areas. Western coal occurs in thick seams, requiring on the average that between 25 and 70 acres be disturbed to produce one million tons of coal, equivalent to 0.02 quad (National Academy of Sciences, 1974). If the land is reclaimed after five years, then the amount of land disturbed during the mining of one million tons annually is five times this figure or approximately 250 acres. Eastern and midwestern coal occurs in thinner seams, averaging about 300 acres per million tons produced (Council on Environmental Quality, 1973). If one again assumes that the land will remain disturbed an average of five years during mining, then 1500 acres is impacted to produce an annual output of one million tons of coal. These numbers are to be compared with a land requirement for energy plantations of about 50,000 acres to produce the fuel equivalent of one million annual tons of coal (Alich and Inman 1974).

There is little doubt that the impact of widespread use of terrestrial energy plantations (about 3 annual quads in the solar emphasis case, 7 million acres) will be a significant one. The availability of water and land for energy plantations is an important issue. The two regions in the United States most likely to be suitable for biomass plantations are the Southeast and the Southwest. There are ample supplies of water in the Southeast, but large land areas for energy plantations (about 250 square miles to supply fuel for a 1000 MW(e) power plant) are lacking. (High collection costs from many small biomass farms tend to make the use of a large number of small farms impractical.)

The Southwest has large land areas that could be devoted to energy plantations, much of them managed by the federal government. For this reason, some authors have concluded that the most likely sites for energy plantations are in the Southwest (Alich and Inman, 1974). Between three and eight acre-feet of water are required as irrigation water per acre each year (Whitaker, 1970; Alich and Inman, 1974). The lower estimate leads to a requirement of 150,000 acre-feet of water each year to produce the fossil fuel equivalent of one million annual tons of coal; this is a quantity of water very much greater than that needed to extract an equal amount of coal or convert it to gas or electricity. For example, the quantity of cooling water to process one million tons of coal in a power plant with a wet cooling tower is approximately 2000 acre-feet. For the reclamation of land underlain by one million tons of western coal, only about 35 acre-feet per year are required (National Academy of Sciences, 1974). Alich and Inman, 1974, have concluded that to establish energy plantations in the Southwest, almost all of the irrigation water would have to be imported from outside the region. In addition to problems of water availability for energy plantations, other important issues are the competition with productive uses of land for wood and paper products and for agriculture, and the potential ecological consequences of changes in land-use patterns for the very large land areas required by the plantations.

b. SOLAR SPACE AND WATER HEATING

Solar space and water heating make up the largest part of the solar energy contribution to the solar emphasis case; a total of 22 quads (resource energy equivalent) or about 50% of the solar energy in the scenario. The solar energy is used for rural space and water heat, residential and commercial space and water heat, and to produce industrial low-grade steam. Although each of these applications has different environmental impacts, for our purposes it is convenient to treat them together. This is possible because the solar emphasis case assumes that problems of specific systems (e.g., aesthetic impacts) will be resolved over time. (There appears to be no major reason to question this assumption.)

Thus, we are interested in determining if there are significant systems problems of an environmental nature resulting from the widespread use of solar energy for space heating and cooling. Two major issues, both dealing with the materials requirements for the solar energy systems are: (1) will solar material requirements place heavy demands on the various metals industries, and (2) are there any significant secondary environmental impacts associated with the production of materials for solar energy?

A useful way to analyze the first question is to begin with the materials that go into a typical space heating system and then project that system into the nation in quantities consistent with the demand for solar energy. This is a simplification, because, in fact, a large number of systems containing a variety of materials will be used, but the simplified argument can indicate the magnitude of expected increases in materials demand.

A typical solar heating system with backup used in the model calculation delivers about 46 million Btu per year of heat to the home. 70% of this, or about 32 million Btu per year, comes from the solar heating component of the system. In our accounting system, the 32 million Btu corresponds to about two and one half times this figure or 80 million Btu, fossil fuel equivalent. (The exact conversion into fossil fuel equivalent depends on the space heating options that are replaced.)

We adopt the materials composition of the space and water heating system from Energy and Environmental Analysis (1976a). The material amounts in our system are scaled down by two-thirds to account for the fact that our solar energy system is smaller, has more backup, and does not include water heating. The quantities of materials in our system are approximately: 550 pounds of aluminum, 1100 pounds of steel, 800 pounds of glass, and much smaller amounts of other materials.

The relevant question is: how large a part of the total materials production in 2020 will have to be devoted to solar energy systems. Note that the solar emphasis case has 9 quads of solar heating in 2000 and 18 quads in 2020. This corresponds to an increment of about one-half quad per year of solar heating in 2020. From the numbers presented above, one-half quad requires about 1.7 million tons per year of aluminum, 3.5 million tons per year of steel, and 2.5 million tons per year of glass in 2020. For aluminum, which is by far the most likely of the three to be constraining, this demand corresponds to about 7% of annual aluminum production for solar space heating in 2020, assuming a 3% annual growth in aluminum production. This is a significant quantity of aluminum and it necessitates an increase in the growth of the aluminum industry, but it is not a quantity of aluminum that is likely to overwhelm the domestic aluminum capacity. It does raise the issue of where the aluminum will come from. Although much of the U.S. aluminum and bauxite consumption is imported (from Jamaica, Surinam, Canada, and Australia), there are vast supplies of lower grade ores in domestic clays that some authorities believe will be refined commercially before the turn of the century. If the aluminum is not available, then the space heating systems can be designed with less aluminum and more steel, plastic or glass.

The basic conclusion is that materials requirements for solar heating are significant enough to merit attention but that substitutions of materials and a growing minerals industry in the solar emphasis case should be sufficient to avoid major materials constraints to the scenario.

The second question, dealing with air pollution, can be addressed using the same example heating system as above. A comparison of the energy to produce the system versus its energy output provides an answer to this question. Aluminum requires about 200 million Btu per ton in its production (Federal Energy Administration, 1974). The other materials used in quantity require far less energy (about 17 million Btu per ton of glass and 40 million Btu per ton of steel). Thus, the solar system requires about 90 million Btu, fossil fuel equivalent, for its production. Assuming that the system lasts 30 years, it will deliver about 2400 million Btu, fossil fuel equivalent, over its lifetime. This is about 25 times the energy that goes into the system. Thus, if the same energy sources that are used to produce the materials are displaced by the solar heating system, a 25-fold reduction in air pollution emissions can be expected. (Emissions during the mining of the minerals also occur, but accounting for these emissions does not change the argument). Furthermore, after the lifetime of the solar heating system, the materials can be recycled without difficulty. Recycling requires only a small fraction of the energy to produce the material from ore.

c. SOLAR ELECTRICITY

There are two major environmental issues regarding the use of terrestrial solar systems to produce electricity; the net impact of the materials production cycle and land use impacts. The materials production cycle should not represent a major problem, for the same reasons given for solar space and water heating systems: the net production of emissions averaged over the lifetime of the solar energy system is small on the basis of unit energy output of the system producing electricity. However, land use is a significant issue for solar options producing electricity. This is because large land areas must be devoted to the collection of solar energy. To understand the significance of the land use impacts of solar energy systems to produce electricity, it is useful to compare the use of land for these systems with those of the other major energy systems.

Land used for energy is rendered, at best, marginally useful for other purposes. Although it may prove feasible to site energy facilities in areas already unattractive or uneconomical for other uses, competition between energy production, agriculture, industry, other resource extraction activities, and residential and recreational uses will constitute an important issue in the energy policy area. For many kinds of facilities, factors such as the proximity of abundant fossil fuel resources, the availability of water and transportation networks and available sunlight, will dominate siting decisions; in other words, it will often be impractical or expensive to locate energy facilities where they do not interfere with human settlements, agriculture, recreational lands, forests and municipal watersheds, and so forth.

Two kinds of land use have to be taken into account. Fixed land requirements describe the land on which permanent facilities and certain kinds of waste disposal plants rest. Incremental requirements, on the other hand, are those for which land is mined for a resource and can be returned to approximately its original state, if proper reclamation practices are carried out.

Figure 3-3 illustrates the total land requirements for solar and coal-fired electric power plants. We have included biomass for comparison to indicate the very large land consumption of biomass relative to the other solar energy systems. To compare permanent and incremental land use in the same figure, we make the assumption that there is an average of five years during which the land is in need of reclamation. This assumption may be considered optimistic by some; if less than full reclamation is obtained or greater than five years required for reclamation, then the amount of land increases accordingly. The Council on Environmental Quality (CEQ, 1973) lists the land requirements for coal-fired power plants. Energy and Environmental Analysis (EEA, 1976b and 1976c) provided the estimates of solar plant size.

Great care should be used in interpreting Figure 3-3, as important qualitative differences in the use of land are not reflected in the numerical presentation of the data. The use of land for a solar collector is different from that for the mining of coal. The land under the collector could, in some cases, be used for purposes not associated with the solar energy system. This is especially likely for solar photovoltaic systems that, if they ultimately become commercial, could be widely dispersed and located in sites that are already serving

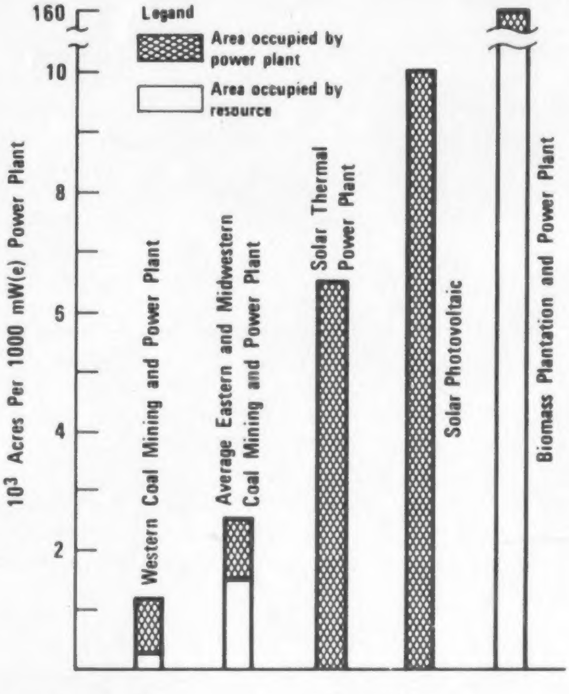

Figure 3-3 Land Requirements for Electricity Production

other purposes. Furthermore, as efficiency improvements are made in solar systems, the land use will decrease somewhat. Nonetheless, because of the diffuse nature of sunlight, siting and land use issues of solar electric installations are a significant problem that will have to be dealt with as the solar emphasis scenario is implemented. As is evident in Figure 3-3, this is an especially significant problem for biomass plantations, whether it is used to produce electricity or a liquid or gaseous fuel.

To complete the discussion of the environmental impacts of solar electric systems, we summarize the impacts of OTEC. OTEC may be one of the more likely solar electric processes. OTEC would have several kinds of environmental impacts. First of all, cold deep water which OTEC brings to the surface is usually rich in inorganic nutrients. This artificial upwelling combined with a large OTEC platform, which marine life forms could use as shelter or a place of attachment, would cause a large increase in biological productivity in the vicinity of an OTEC plant. This biological productivity is taken as a mariculture credit against OTEC costs, but it also means serious biofouling problems for OTEC heat exchangers. Water jets for cleaning heat exchangers would be environmentally benign, but if it is necessary to use large quantities of biocides such as copper sulfate, OTEC could have negative impacts on ocean life.

The second class of OTEC impacts is associated with the energy transport material–ammonia or liquid hydrogen. Liquid hydrogen has safety problems similar to liquid natural gas. Both materials could produce immense explosions in ports if mishandled. Ammonia is less explosive, but it is poisonous to marine life. However, an ammonia spill would not be nearly as environmentally damaging as an oil spill.

The third class of OTEC envionmental impacts is associated with on-board production of inorganic chemicals. Terrestial production of these chemicals produces large quantities of air and water pollutants. While pollution treatment is possible at sea, it would be very expensive. There would be great economic temptation to make OTEC competitive by skipping pollution treatment. Arguments about OTEC pollution follow the same line of reasoning as the issue of moving power plants out of cities to rural areas. There are environmental benefits to diffusing pollution and moving it away from people, but these benefits must be weighed against damaging a now nearly pristine environment.

d. CONCLUSIONS

Significant reduction in the use of nonrenewable resources and modest environmental benefits can be expected to result from a solar energy future such as that portrayed in the solar emphasis case. These advantages provide an immediate motivation for those who advocate a major role for solar energy in the nation's energy future. A comparison of the solar emphasis and the reference cases reveals that, based on the assumptions of the scenarios, solar energy serves primarily to replace coal consumption. As advanced fossil fuel systems are commercialized, incorporating process changes that reduce emissions to the environment, the relative environmental benefit of the solar emphasis case is reduced. Examples of such technologies that reduce fossil fuel impacts are the fluidized bed combustor, fuel cells, and combined cycle turbines that use gas produced from coal.

It is instructive to analyze the degree to which the solar emphasis case alters the implementation measures required in the reference case to deal with environmental impacts. Because the level of growth of nuclear power is similar in both scenarios, nuclear impelmentation measures of the reference case are required in the solar emphasis case as well. Most of the fossil fuel implementation measures, in the reference case, focused on the development of energy sources in the West. The growth of western energy production is very rapid for the solar emphasis case as well: 47 quads per year of western coal in the solar emphasis case in 2020 is about 3 billion tons per year or about five times current *total* coal production in the United States. As a result, the implementation measures in the reference case are generally applicable to the solar emphasis case as well. Analysis of the scenario results suggests that the fossil fuel implementation measures can, in many cases, be delayed by several years, but the major issues that society must confront regarding the development of fossil fuel resources are very much a part of the solar emphasis case we have described. Thus, for those individuals who are likely to oppose the implementation measures of the reference case, social decisions to implement a solar energy future may provide some limited relief from the measures but do not greatly alter the nature of the decisions that must be made to achieve the fossil energy development.

4. The Low Demand Case

The low demand case avoids many of the measures required in both the reference and solar emphasis cases to mitigate environmental impacts or make the scenario happen. This does not mean that there are no environmental issues that will require public discussion and decision making. It does, however, mean that the element of choice among supply options is sufficient to permit great flexibility in the resolution of environmental problems. For example, the low demand case has essentially no increase in eastern coal production and a 10 quad increase in western coal production between the present and 2020. Although this is the least costly choice under the assumptions of the low demand case, the difference in cost of usable energy between the two regions is not great and social decisions could be made to modify this pattern of resource development.

The low demand case has a continuation of nuclear power growth, albeit at a lower rate than for the other two cases. This implies that the nuclear implementation measures will be needed in the low demand case, but the time over which the decisions must be made is extended. Specifically, the slower growth rate of nuclear power allows more time for the solution of the troublesome safety and waste disposal problems. Furthermore, if the social decision is made to halt nuclear power growth at some future time, the low demand case can reasonably accomodate to this without significant disruption in the energy supply system.

In summary, the low demand case eliminates the need for many of the implementation measures of the other two cases and, for those measures not eliminated, provides great flexibility among supply choices.

B. ECONOMIC/INSTITUTIONAL IMPLICATIONS OF THE SCENARIOS

1. Overview

The reference case—and as we discovered, the solar emphasis case as well—was dominated by environmental considerations. In surveying economic impacts, we call particular attention to the economic impacts of the low demand case. There are and will for some time remain uncertainty about the degree to which low growth in energy demand is compatible with traditional growth in the economy. However, there are enormous opportunities for energy conservation in the United States without lifestyle changes and even greater opportunities with changes in the way we live. Although justfiable fears exist that the immediate impact of higher energy prices could be unemployment, the long term prospects for low energy growth and high employment appear not alarming. The effects of government economic policies on employment and economic activity will be much greater than the effects of higher energy prices. Measures to compensate the poor and guard against the regressive nature of an energy tax are necessary. Two clear cut problems remain: industries producing products of high energy content will lose markets and, in many cases, may be forced into bankruptcy; energy industries will achieve greatly reduced growth rates and may be expected to decline substantially in profitability. A very important determinant of the acceptability of the low demand case is the degree to which citizens voluntarily choose to alter their lifestyles and live more frugally versus the degree of coercion needed to implement low demand.

The special economic problem of the reference case, much reduced in the low demand case, is that of oil imports. The economic assumptions behind the reference case lead to a growth in the Nation's dependency on oil imports until after the turn of the century. For the solar emphasis case, the problem of oil imports continues to plague the nation.

A wide range of options exist to implement the solar emphasis case, running the gamut from solar RD&D to the redesign of utility rate structures to the elimination of subsidies of competing fossil fuels to subsidies for solar energy. Few of these options have as yet been carefully explored, but many of them appear to offer important benefits. Raising the price of fossil fuels (through deregulation, taxes, or removal of subsidies) is a critical implementation measure for any of the scenarios, if substantial solar energy market penetration is to be achieved. The outright subsidy of solar energy is a disincentive to energy conservation and raises difficult questions about how such a subsidy could be implemented equitably. As solar energy becomes competitive with fossil fuels, the owners of the scarce fossil fuel resources and energy producers lose "economic rent." That is, the extra benefits the owner of the scarce resource derives from expectations of higher prices in the future resulting from increasing scarcity are reduced as solar energy becomes a significant contribution to the nation's energy supply.

2. Economic Impacts of Low Demand Case

Just as environmental impacts and implementation measures were a major issue for the reference case, so are the economic impacts and related implementation measures a major issue for the low demand case. The priority issues are:

- Will low growth of energy demand curtail economic growth? If so, to what extent and which economic activities are most likely to be affected?
- What is the impact of low demand on the consumer?
- Will certain regions be especially economically hard hit under conditions of low energy growth?
- To what extent is low energy growth likely to reduce dependence on foreign oil?
- Are there other longer-term advantages or disadvantages to low energy growth where the payoff is beyond the time horizon of the study?

We should recognize the highly charged and emotional nature of the debate over these issues. On the one hand, advocates of continued energy growth often suggest that reduced demand will cause an economic depression because a healthy economy is dependent on adequate energy supply. On the other hand, advocates of strong energy conservation measures often point to the great "fat" or "waste" in the system and indicate that much of this could be eliminated through appropriate, economically based incentives.

It is essential to distinguish between short-term and long-term impacts of reduced energy growth. Considerable misunderstanding, if not acrimony, has resulted from a failure to make this distinction. In many cases, debates about the economic impacts of different levels of energy growth have featured discussants on one side dealing with short-term economic dislocations versus discussants on the other side emphasizing the longer term potential for energy conservation taking place without major economic disruption. To treat the issue, we first analyze the credibility of the low demand scenario being designed to minimize economic disruption; we then turn to the transition problems of reduced energy demand.

a. LONG-TERM EFFECT ON INDUSTRIAL ACTIVITY

Substantial increases in energy prices through taxation were assumed as the driving force of the low demand case. To analyze the effects on economic activity, we focus on the industrial sector and industrial energy consumption. The higher energy prices cause reduced demand both through cost effective energy conservation and through changes in consumer demand for products resulting from the higher prices of energy-intensive products. A plausible case can be made that a part of the share (half or more) of the reduced industrial demand in the low demand case can come about through cost effective conservation measures. This argument is supported by the general coincidence of results from (1) the economic analysis that was used in Chapter 2 to derive industrial energy growth for the low demand case and (2) assessments independent of this work that have looked more closely at technological possibilities for industrial energy conservation. Specifically, the economic analysis in Chapter 2 projected an industrial energy demand of 60% less than the reference case in 2020, based on a tripling of energy prices in constant dollars over the next 45 years. Other studies have suggested that as much as 25% to 40% of industrial energy use consumption could be reduced in the next ten to twenty years if cost effective energy conservation measures are adopted in industry.*

To accomplish this reduction in industrial energy growth, the major approaches include (1) improved systems for generating industrial process steam, which accounts for about 40% of total industrial energy consumption, (2) more efficient industrial processes, particularly in energy-intensive industries such as aluminum, paper, and cement production, (3) use of total energy systems, particularly cogeneration of electricity and steam, and (4) materials recycling.

Both the energy conservation measures and higher energy prices in the low demand case cause shifts in consumer preference. The prices of energy-intensive materials and products will rise, in proportion to their energy content. As relatively easy energy conservation measures are taken in the short term (the next ten years) and as more capital-intensive measures are taken over the intermediate term (until the end of the century), the increased energy costs will also induce shifts in industry output to less energy-intensive products. Thus, the low demand case implies a gradual and increasing change in the mix of industrial activity in the U.S. The industries with products of the highest energy content (energy intensiveness measured in thousands of Btu per dollar cost of the product shown in parentheses) include lime (470), hydraulic cement (410), primary aluminum (370), alkalis and chlorine (370), electrometallurgical products (280), brick tile (280), inorganic chemicals (230), industrial gases (190), and paper and pulp mills (130), according to the data cited by the Conference Board (1974). Even after these industries adopt conservation measures, they will find themselves at a competitive disadvantage (compared to their situation in the other two scenarios). The higher energy prices and the resulting energy conservation retard growth in selected industries. Those industries listed above and others like them, comprise stakeholder groups that, in their own self-[illegible] are likely to oppose higher energy prices. To th[illegible]at that the higher energy prices in the low demand case are imposed gradually, these industries will have time to make adjustments, but these adjustments will not necessarily be easy or painless.

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*A number of recent studies have assessed the current potential for energy conservation in industry. An extensive data base on energy consumption in nine industries has been prepared by the Federal Energy Administration (1974a). A report prepared for the Ford Foundation Energy Policy Project by the Conference Board (1974) estimated a reduction in industrial energy demand of 23% below historical trends in the next five years. The Ford Foundation Energy Policy Project in its report, "A Time to Choose," (1974) estimated industrial energy reductions of 40% below historical growth in its Technical Fix scenario for the year 2000. A report by Ross and Williams presents calculations showing that a hypothetical U.S. industry today, using the best available energy conserving technologies, would result in reduced industrial energy consumption of 40%. Similar analyses of energy conservation potential may be found in Schipper (1975) and Cooper and Weinberg (1977).

We have not yet considered the energy industries. Here, without question, growth is curtailed in the low demand case compared with the reference case. The output of the energy industries, although still growing in the low demand case, is only slightly more than 50% of that in the reference case. Although domestic production of oil and gas is extended longer in time in the low demand case, coal and nuclear power are clearly not the growth industries that they are projected to be in the reference case. In spite of reduction in growth potential for energy industry in the low demand case, energy industries are likely to be able to find several ways of adjusting. In the first place, coal production will increase faster than it has in the past several decades. Secondly, nuclear production continues to increase–albeit more slowly than expected in the other two scenarios. (Alternatively, if the social choice toward reduced growth is coupled with the decision to curtail nuclear growth, then coal production will expand to make up the difference). Furthermore, the major oil companies are international companies with internationl markets, and it is likely that they will direct considerable effort at markets outside of the United States if growth in the U.S. markets is reduced.

The problems of unemployment and inflation require careful analysis, because they are often assumed to be inevitable consequences of high energy prices. In the long term context (in contrast to dislocations that will occur in a transition period to low energy growth), unemployment may not be a major problem for at least three reasons: (1) cost effective energy conservation can serve to create new jobs,* (2) to the extent that the output of the economy is shifted to less energy-intensive products, workers can be relocated rather than unemployed(and, to the extent that less energy-intensive industries are more labor intensive, employment would increase), and (3) national economic policy is a far more potent tool for reducing unemployment, if it is so directed, than energy policy. There may be some dispute about the first two points. However, even if reduced energy growth were to cause unemployment in certain sectors of the economy that are not compensated for by increased employment in others, the long-term influence of government investment decisions and fiscal and monetary policy may be expected to have substantially greater bearing on jobs than higher energy prices.

The basic premise of the low demand case is that energy prices approximately triple relative to other prices in the economy. Because energy represents only about 5% of the gross output of the economy, a tripling of energy prices means only about a 10% rise in the overall price level *if* all other prices are frozen. This theoretically small impact of energy prices was tested when OPEC raised oil prices in 1973. The sad result was that the oil price rise contributed to dramatic inflation and a recession. The inflation was caused because other prices were not frozen. When oil prices rose, oil users passed that price increase along to consumers, and the consumers as wage earners tried to pass the price increase back as higher wages. Everyone knew that the nation had suffered a real drop in standard of living, but no individual or group was willing to accept his share of the decline. When the Federal Reserve tried to stop the price spiral by reducing the supply of money, this contributed to the deepest recession since 1932 on top of the highest sustained rate of inflation since World War II.

Energy taxes are different from increased payments to other countries for imported oil. There is no need to suffer a general drop in standard of living because the government can return the energy tax as a general income tax rebate or reduction. This is in contrast to the exodus of money and economic damage when oil imports are high and a price rise is imposed from outside the country. (Note that in the low-demand case, fuel imports are very low.)

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*In fact, there are indications that expenditures for cost effective energy conservation processes can create more jobs than equivalent expenditures for energy, because the energy industry has such low employment per dollar of revenue (Schipper, 1975).

However, our 1973 to 1975 experience should make it clear that even though the average person would be no worse off with an energy tax plus compensating general tax reduction, the net effect could well be inflationary. This is because there will be a tendency for individuals and groups to accept the tax rebate but also to attempt to pass along the cost of the energy tax increase. It would require great national self-control, of a sort which has rarely existed outside of wartime, to resist turning the energy tax into another general round of inflation.

Even if the inflation could be avoided, not everyone would be uniformly well off. Because serious energy conservation means changing living habits and changing residential and industrial locations, some disruption is an inevitable part of a major shift to energy conservation. These kinds of localized problems will be more important than any problems that increased energy prices bring for the economy as a whole. (The exception to this statement is competitiveness of U.S. industry vis-a-vis low-energy-price countries.)

The question should not be will energy conservation cause disruption, but will the disruption from energy conservation be worse than the disruption from maintaining energy growth?

b. THE TRANSITION PERIOD

The past two or three years have witnessed a decline—not only in the growth of energy consumption—but in the total quantity of energy consumed in the United States. High inflation and unemployment were also economic facts of life in these years. There is evidence to link these trends, but most observers agree that energy problems and particularly higher energy prices (not caused by U.S. government taxation) compounded the economic problems. Continued decline in energy growth (or consumption) will cause dislocations in the economy and require adjustments in both the private and public sectors. During periods of economic expansion, when the policy of the government is to dampen economic growth, measures to promote a transition to a low energy demand scenario are probably most easily effected. In periods of recession or high unemployment or both, a suitable balance between economic policy decisions and the energy tax decisions consistent with a social choice in favor of the low energy demand case will be more difficult to achieve.

Clearly, prevailing economic conditions will strongly influence the efficacy and desirability of methods to achieve a low energy growth case, even if the social decisions are made that would establish reduced energy growth as a long-term objective. This is a subject that is worthy of considerable scrutiny and analysis.

c. EFFECTS ON CONSUMER CHOICE

(1) Transportation and Residential/Commercial Energy Demand

The discussion above dealt with the effects of the low demand case on industrial activity. The argument suggested that the low energy growth case would impose constraints on the products available to the consumer, with an increase in cost of highly energy-intensive goods. Similar limits are apparent in the use of energy both in the home and in transportation. The use of energy in the home is least curtailed in this scenario: saturation of most appliances now known can occur and no particular deprivation of energy-consuming activities within the household is apparent. (Air conditioning, although not saturating the market, could double by 2020 in the low demand case.) However, to achieve the reduced levels of residential/commercial energy consumption in the low demand case, substantial measures to reduce heating and cooling needs of buildings must be taken. These include careful attention to the design of buildings to utilize the environment to reduce space conditioning needs (e.g., "passive" solar heating), ample insulation, and related energy conservation measures as well as alteration of energy-wasteful habits within the building. The low demand case also implies that an increasing fraction of the population lives in apartment dwellings or multiple family housing, particularly after the turn of the century when much of existing housing stock has been made less energy consumptive.

Energy consumption in transportation actually declines somewhat in the low demand case between the present and 2020. Such a phenomenon represents a dramatic change in lifestyles accompanied by major technological improvements to conserve energy. The scenario has small cars of high energy efficiency and also incorporates major shifts of passengers to buses and rail. For public transportation to handle a significant part of travel, most living arrangements would have to be in high density areas. Furthermore, commuting travel would have to be substantially diminished. Air travel, though consuming twice as much energy in 2020 in the low demand case as today, has a growth rate much reduced from that of historical projections.

(2) Energy Prices and the Consumer

The higher prices for energy in the low demand case are a cause of particular concern to the consumer, and especially to the poor. The most recent data on consumer expenditures on energy by income group dates to the time period 1972-1973, before the most recent increases in energy prices (Newman and Day, 1974). At that time, the lowest 18% of households in income, falling into the U.S. government category "poor," spent over 15% of their income on energy. The next economic group, termed "lower middle" and comprising over 40% of households, spent over 7% of their income for energy. The "upper middle" and "well off" groups, each about one-fifth of the households, spent 6% and 4% of income on energy, respectively. The problem of rising energy prices, especially for the "poor" and "lower middle" groups, is undoubtedly more serious than these numbers suggest: (1) since 1972-73, energy prices have increased much faster than personal income, meaning that the fraction of income spent on energy has increased, and (2) the quoted percentages of income spent on energy are only for direct purchase of energy by the consumer, and does not include the energy incorporated in products purchased.

Thus, it would appear that the energy tax used to implement the low demand scenario would adversely affect the consumer. Furthermore, the impact is regressive, affecting the poor much more than the well-off. Although the problem of the energy consumer appears to be a serious one when viewed in this light, it can and must be dealt with in the low demand case through other governmental policy measures. In a period of rising energy taxes, there needs to be a coupling between general tax policies, social policies, and the energy tax policy. A tax of one dollar per million Btu will increase government revenues by from $75 to $100 billion dollars per year. An implementation measure required to make the low demand case plausible is the return to the taxpayer of a sizeable part of these tax revenues to avoid the otherwise regressive nature of the taxation. As pointed out earlier, a policy that combines energy taxes with some type of tax rebate (not necessarily linked directly to energy use, but designed to protect the lower income groups) results in real pressures to reduce energy consumption, because the tax rebates can be spent in any way and the consumer sees a rise in energy prices relative to the prices of other goods. The basic problem, so far as the consumer is concerned, is his *perception* of hardship caused by higher energy prices, in spite of the fact that carefully balanced government policy could be designed to reduce or eliminate most of these hardships.

d. CONCLUSIONS

A pattern has emerged in the analysis of economic impacts of the low demand scenario. If higher energy prices are acceptable to the American people and are generally effective in reducing demand growth, then the scenario can occur without the government playing a forcing role to regulate or control growth. At least three major benefits result from the scenario: (1) the reduction or elimination of many of the most adverse of the environmental problems of higher growth, (2) increased protection from interruption of insecure foreign sources of oil, and the associated threat of economic disruption caused by such an interruption, and (3) an extension of time in which alternatives to our fossil fuel resources can be found, thus potentially diminishing the severity of ultimate problems of transition to other energy forms.

If, on the other hand, the public does not give high priority to these benefits of reduced energy growth, then it is hard to envision a freely elected government adopting such policies. Inextricably involved in this choice is the fear of many persons that reduced energy growth will cause severe limits on economic growth.

Although the preceeding arguments suggest that this need not be the case, the final story on economic impacts will only be known after policies have been implemented and the economy has had time to adjust.

3. Economic Impacts of the Reference Case

The economic problems of the reference case are generally those that the U.S. has been dealing with in the recent past. Issues such as capital availability for energy development may cause periodic difficulties, particularly by contributing to higher interest rates that increase the difficulty of raising money for other industrial activities (e.g., construction). However, just as the federal government has numerous economic policy tools to deal with essentially economic problems in the low demand case, here too government policy can be expected to play a predominent role. In particular, the majority of recent analyses of the short-term capital availability problem have come to the conclusion that the most important factor affecting capital availability is the degree of surplus or deficit of the federal budget. These analyses conclude that if the federal budget can return to a modest surplus, problems of capital availability can be avoided (Bosworth, Duesenbury, and Carron, 1975). Although these studies are optimistic in terms of overall economic aggregates, the problem of corporate ability or willingness to increase its borrowing may depend as much on the nation's psychological climate as it does on economics.

The problem of oil imports is an extremely serious one over which the federal government has limited control. The reference case has a steady increase in oil imports from the present to 2010, after which time synthetic liquid fuels are projected to take up the slack. Thus, the potential for supply disruptions of imported oil will tend to grow in the reference case.

Both the Federal Energy Administration and the Department of Commerce, using different estimating procedures, estimated a loss in GNP of between $10 billion and $20 billion during the 1973-74 embargo (FEA, 1974). The automobile industry and support industries suffered the most severe employment and economic losses during the embargo. Total unemployment attributed to the embargo was 500,000, with the Mid-West primarily impacted. The analyses suggested great uncertainty about longer run impacts of the OPEC embargo or about the economic impacts if the embargo had continued. Other considerations of primary importance are the effects of an embargo on the economies of Western European nations and Japan, who are more dependent than the United States on oil imports. The many interdependencies between U.S., European, and Japanese economies increase the sensitivity of the U.S. economy to an embargo.

One countermeasure to an embargo, already begun in the United States, is the development of a petroleum stockpile. Because a substantial fraction of imported oil is refined outside of the U.S., a stockpile of crude oil may not provide very complete protection against a future embargo without an expansion of refining capacity as well.

There is general agreement that an increasing level of oil imports poses a potentially serious economic problem to the United States. If the OPEC cartel collapses, then the severity of the problem is much reduced. On the other hand, if the cartel remains strong and a future embargo occurs (for political or other reasons), then increasing levels of oil imports exacerbate the economic consequences of an embargo. Increased dependency of the United States on oil imports could increase the likelihood of military action in the event of an embargo.

4. Economic Impacts of the Solar Emphasis Case

a. IMPLEMENTATION MEASURES

The major difference between the reference case and the solar emphasis case is that substantial incentives are given to solar energy to encourage its growth in the latter case. Considerable penetration of solar energy, approximating 11 quads of resource energy in 2020, occurs in the reference case, under the assumption that the most obvious of the government policies keeping fossil fuel prices down (e.g., control of natural gas prices) are removed in the next 5 years. The reference case also assumed that some of the institutional barriers for space heating uses of solar energy would also be removed; zoning regulations that make implementation of solar energy technology difficult, building codes, resolution of sun rights issues, growth of a building industry that has the skills to construct buildings with solar energy, etc. All of these changes, which admittedly will not take place easily and will require considerable trial and error before achieving acceptance, constitute relatively passive measures probably requiring limited government intervention.

The solar emphasis scenario requires much more than this relatively passive role of the federal government. The active government role in the scenario can be understood by noting that some combination of the following implementation measures would be required:

- Success in solar RD&D.
- Elimination of government policies that reduce the price of fuels that compete with solar energy (also required in reference case to bring in 11 quads of solar energy).
- Government low interest loans to promote the early use of cost-effective solar heating systems.
- Changes in the rate structures of electric utilities.
- Government support for solar demonstration plants.
- Direct subsidies to close the cost gap between solar and competing fuels.

Each of these points is addressed separately.

(1) Success in Solar Energy RD&D

Success in reducing the cost gap between solar energy and competing energy systems through solar energy research and development is probably the most straightforward way to achieve a solar energy future. Although there is no way of assuring success in reaching competitive cost targets for solar energy systems, the solar emphasis case requires that a vigorous effort be carried out to achieve this end.

(2) Elimination of Government Policies that Reduce the Price of Fuels Competing with Solar Energy

Subsidies and price regulation of fossil fuels must be removed to obtain significant solar energy penetration in any of our scenarios. This implementation measure is assumed for all of our scenarios, so it is not further discussed here.

(3) Low-Interest Loans

The estimates in Chapter 2 indicate that solar heating of residential and commercial buildings and solar water heating are competitive in many regions of the nation if the prices of competing fuels are largely deregulated. This does not mean, however, that cost-competitive solar systems will be chosen in the market place. Because solar energy systems are capital intensive, many consumers concerned about the higher initial cost of the solar system will not choose it even though its life cycle cost is lower than that of a competitive system. In some cases this may be out of ignorance of the advantages of lower life cycle cost; in other circumstances, the consumer cannot easily afford the higher first costs of the solar system. Estimates have been made that discounts in excess of 25% are needed to provide an effective incentive for solar systems in the residential market (FEA, 1976). Furthermore, as noted in Chapter 2, ceilings on mortgages for homes limit the ability of the borrower to borrow for the construction of capital-intensive solar energy systems. For most industrial and many commercial applications of solar energy, the principles of life cycle costing are well understood and the raising of capital is not so difficult as for the residential user. Loans at interest rates of ordinary mortagages or below are likely to be needed to provide initial impetus for solar space and water heating in the solar emphasis case. (Note that the loans in the scenario are instituted *after* substantial measures have been taken to deregulate energy prices. Without deregulation, low interest loans are insufficient to bring about widespread use of solar energy.)

(4) Utility Rate Structures

The rate structures used to determine the costs of auxiliary heat for solar space heating systems can have a significant impact on the economics of solar heating. It is certainly possible that rate structures could evolve which severely handicap solar, so that the careful design of rate structure for both gas and electric utilities will be an important implementation measure to encourage solar use. There is growing interest in investigating the complete topic of the relationship between rate structures and solar heating market penetration (for example, see Lorsch, 1976).

One somewhat simplified example will serve to show some of the important issues and will demonstrate how present rate structures can encourage electric utilities to work against solar energy. If a utility has its peak load during the summer to meet air conditioning demand and if solar energy systems contribute the greatest during the winter to meet heating demand, then the use of solar energy will cause the utility to generate and sell a larger percentage of its electricity during peak periods. Since electricity generated during peak load periods is more expensive to produce than base load electricity (by as much as 8 times [FEA, 1976]) and since the present rate structure does not reflect this difference in cost, the widespread use of solar energy in this example will result in a loss in profit to the utility or require hearings for utility rate increases.

Very high market penetration of solar systems can complicate and even reverse this situation. It would be possible to reach the point where solar systems relying on electrical backup became so common that the peak load for a utility would be shifted from summer to cloudy, cold winter days. In this case, the auxiliary heating requirements of the solar heating systems would be the cause of the peak load and therefore could justifiably be exposed to a higher peak load price. Thus, at modest levels of solar penetration, peak load pricing would help solar penetration (by holding down winter rates), whereas at high level of solar penetration (in which the peak loads shifted to winter), peak load pricing could reduce solar heating use.

One potential benefit which solar systems could provide for both gas and electric utilities is through the load leveling opportunities which are created by the inherent storage capacity of most solar systems. These storage systems have the capability of storing thermal energy during night, off-peak periods. For this reason solar heating systems would not necessarily aggravate the peak of even a winter peaking utility provided that these individual systems were appropriated integrated into the utility system to permit system-wide control of the "into storage" heating mode.

Much more research is required in this area to focus on the regional nature of load patterns and generation system characteristics. It is clear that utility rates, both gas and electric, are a vital determinant of solar penetration.

(5) Government Support for Solar Demonstration

The solar emphasis scenario assumes a government policy that will nurture new solar energy technologies through research, development, and demonstration phases. This applies not only to the solar energy technologies but also to energy storage systems that are extremely important to the economics of solar electricity. This means not only an active role by the government in supporting demonstration facilities for promising solar systems, but also a government procurement system that is designed to encourage the use of solar energy systems in government buildings whenever possible. The use of government procurement, for both the civilian and military applications, can contribute significantly to the acceptance of new solar energy systems in the marketplace.

(6) Direct Subsidies to Close the Cost Gap

An additional option to achieve the solar emphasis case is to provide a subsidy to solar energy. The results of the subsidy calculation indicated that such a subsidy would cost about $30 billion per year (beginning in 1990 when the solar electric technologies are assumed to be commercially available) to achieve the solar emphasis case of 44 quads solar penetration by 2020. The magnitude of this subsidy is critically dependent on performing the subsidy calculation. Thus, to the extent that such measures as achieving successes in solar R&D and changing the rate structure of electric utilities are successful, the magnitude of this subsidy is reduced. Furthermore, if the estimates of competing fossil energy prices are low, then a smaller subsidy than indicated would be required. On the other hand, observers may believe that the base economic assumptions for solar energy are low. If so, then the magnitude of the subsidy is increased. The general point is that a *rough* estimate of a subsidy for solar energy puts this subsidy at the $30 billion per year level, and this provides a useful benchmark against which to compare the benefits of an ERDA-49 level solar energy future.

b. IMPLICATIONS

Like the reference case, the solar emphasis case is predicated on assumptions of economic "business as usual". Oil imports in this case are only slightly lower than the reference case. Thus, the potential for supply interruptions discussed in the reference case applies to the solar emphasis case as well. The solar emphasis case simply does not reduce oil import dependency significantly. Capital availability problems should not be significantly different for the reference and solar emphasis cases. Although solar energy is more capital intensive than much present energy technology, it is competing in the future with very capital-intensive synthetic fuel plants and with substantial investments in distribution systems (not needed in nearly as great a measure for many solar applications).

Thus, the major economic impacts of the solar emphasis case are those of the implementation measures discussed above. As will become apparent in the discussion of stakeholders, the distribution of costs and benefits is a major issue, and there are significant differences in the allocation of these costs and benefits, depending on which of the implementation measures are adopted.

C. STAKEHOLDER RESPONSES TO THE SCENARIOS

1. Introduction

As noted earlier, comparison of the three scenarios could be approached in various ways. One approach would be to quantify as many of the impacts as possible and attempt to sort out the costs and the benefits of the scenarios. Because of the uncertainty concerning so many of the variables underlying the scenarios, the exceptional number and variety of impacts, the nonquantifiability of some impacts, and the wide range in differences in the perception of observers regarding the importance of different impacts, such an attempt to quantify a cost-benefit ratio would yield only spurious exactitude. Furthermore, even if such quantification were possible, it is in many cases the distribution of the impacts among different groups in society that is of greater significance than the magnitude of the impacts themselves.

To gain an understanding of the distribution of costs and benefits of the scenario to society, it is necessary to analyze reactions of different stakeholder groups to the scenarios. By stakeholder group is meant a collection of individuals who generally share a common point of view regarding specific decisions because they stand to gain or lose as a result of the decision. Many persons will find themselves part of more than one stakeholder group; stakeholder groups often show great internal diversity regarding their response to a given action; furthermore, membership in and views of stakeholder groups will undoubtably change significantly over time. Despite these sorts of limitations, stakeholder group analysis has come to be recognized as one of the essential tools in technology assessment and similar forms of policy analysis.

2. The Reference Case

The implementation measures for the reference case are discussed from the perspective of four different stakeholder groups:

- Energy producers
- Citizens of energy producing states
- Environmental interests
- Consumer interests.

Other stakeholder groups could be identified, but these are sufficient to illustrate several of the major issues of the scenarios.

The interest groups necessarily represent a range of viewpoints. They should not be presumed homogeneous in their objectives. For example, electric utilities will respond differently from oil companies to many implementation measures. Among oil companies, the independents and the majors are subject to different motivations and objectives. However, under the assumption that the oil companies continue the recent trend of acquiring coal and uranium reserves, some of the interest of the energy producers may be expected to converge over time.

We consider a few of the implementation measures and discuss expected reactions of the stakeholder groups.

a. PREVENTION OF NUCLEAR SITING DELAYS

Energy producers may be expected to applaud measures that would prevent siting delays for nuclear power plants. Electric utilities that undertake the construction of nuclear power plants today spend about

$1 billion for a 1000 MW(e) plant. Delays during construction cause large sums of money to be tied up unproductively. If construction costs continue to escalate, as they have in the past, then postponing a power plant means additional costs. The psychological effect of delays should not be ignored: this makes the organization of the construction project more difficult to control and also increases the uncertainty to the electric utility of meeting projected electrical demand. The owners of the uranium deposits and industries that extract and process uranium stand to gain from measures that overcome siting delays: the market for uranium is made more stable and is more likely to grow. Such conditions will tend to improve the investment climate for all industries dealing with nuclear power, making money easier to raise at lower interest rates for these industries. Stockholders in these companies will profit from these conditions.

In contrast to the energy producers and related interests, the environmental groups are likely to strongly oppose the prevention of nuclear power plant siting delays. Any group within society that opposes nuclear power will lose by this measure. Those who may not oppose nuclear power *per se* but who are concerned with a too rapid growth of nuclear power until safety issues are adequately resolved may be expected to object to the prevention of siting delays.

For environmental groups, the prevention of siting delays poses a problem that goes beyond issues of nuclear power. The legal processes that have been used to delay nuclear power are applicable to any project that is perceived to inadequately safeguard the environment, public health and safety, and quality of life. In many cases, litigation is the only effective mechanism to achieve a degree of public scrutiny over ill-conceived energy development projects. Thus, for example, proposed siting of nuclear power plants in earthquake zones was brought to the attention of the public through hearings and court cases. To the extent that measures to prevent nuclear siting delays erode a legal process essential to the interests of environmental and public interest groups, these groups may be expected to oppose the measures vigorously.

b. SOCIALLY ACCEPTABLE HIGH LEVEL RADIOACTIVE WASTE STORAGE

The selection of sites for long-term storage of high level radioactive wastes will undoubtably set off controversies of major proportion. The nuclear industry must support some choice of sites, as this is a prerequisite for a viable industry over the long run. The basic issues behind the storage problem do not at this time appear subject to resolution: high level radioactive waste storage is a practical necessity to the nuclear power industry; it is a moral issue to those who doubt the possibility of containment for tens of thousands of years. Reaction to this issue is not easily addressed in terms of stakeholder responses, as differing perceptions of the magnitude of the problem cut across all stakeholder groups.

The role of the government in attempting to resolve this issue is likely to be an exceptionally difficult one. The government has undertaken the responsibility to locate, test, and establish the acceptability of sites for the permanent storage of high level radioactive waste. To achieve this in the face of opposition by a substantial minority of the population is likely to place great strains on the institutions of government.

c. SOCIALLY ACCEPTABLE RECLAMATION STANDARDS

The attainment of socially acceptable reclamation standards for strip mined land has the potential of benefiting most of the stakeholder groups. Environmental and conservation groups benefit from the protection of the landscape afforded by the measures.

Although energy producers are subject to higher costs of extracting coal, these costs represent only a very small fraction of the price of delivered energy. A potential benefit to some coal producers is the elimination of the disparity among reclamation guidelines and standards in different states. Those coal producers that already must meet standards will gain in their competitive position vis-a-vis producers in states with less stringent standards; coal producers not presently subject to standards will lose. Reclamation standards will inevitably cause some owners of coal lands to lose a great deal, in those cases in which reclamation up to the levels of the standards is impossible. Uniform national standards could, by making explicit the environmental and land reclamation conditions under which such development can proceed, provide some gain to most coal producers by reducing the uncertainty of coal development.

These measures will undoubtedly cause some rise in prices that consumers pay for energy derived from coal.

d. SUBSIDIES FOR NEW ENERGY "BOOM TOWNS" IN THE WEST

The "boom town" subsidy is chosen as a compromise, to facilitate the development of western energy resources while protecting the fiscal structure of towns in the resource regions subject to rapid population growth and helping to provide public services to serve these regions. It is likely that the energy industries will be called upon to contribute to the solution of social problems in these areas as well. Environmentalists and conservationists, both in the area and elsewhere, are likely to view such subsidies as half measures that will do little to alter the transformation of western coal regions from ranching and semi-wilderness areas into a collection of trailer parks, access roads, new railroad lines, and generally disorganized living communities. Energy industries developing the region will generally profit from a government role that removes some of the burden of these social costs from them. Nonetheless, the costs to industry could be very high, if adequate measures are taken to protect the social environment of these communities. Taxpayer groups may be expected to oppose subsidies to help manage growth as measures that support special interest groups at the expense of all citizens. An alternative, in which the energy industries carry the whole burden and no government subsidies are made available, may be opposed by most energy industries as causing them a very great expense that cannot easily be borne. Environmental opposition to this alternative, for the reasons cited above, can be expected as well.

e. SUMMARY

Consideration of these few implementation measures out of a much longer list reveals a pattern that seems inherent to the reference case: this can perhaps best be summarized by the word "conflict." Although the implementation measures are meant to make the scenario plausible, they are generally controversial, and their achievement requires that substantial obstacles be overcome. Consideration of the implementation measures reveals that economic forces alone are not adequate to bring about the reference case scenario. Social decisions, many of which are likely to be of a divisive nature, must be made, and the will to carry them out must be present.

3. The Solar Emphasis Case

As noted earlier, the basic features of both the nuclear and fossil futures in the reference case are also a part of the solar emphasis case. Thus, the conflicts that are a part of the dynamics of the reference case will not be avoided by chosing the solar emphasis future. It is interesting to speculate that the support for solar energy in this case, while not solving the fundamental conflicts of the reference scenario, will nonetheless serve to placate the interest group most adversely affected in the reference case: the environmentalists and conservationists. Nonetheless, the many similarities between the reference and solar emphasis cases should be recognized.

Although a number of implementation measures are required to provide incentives for the acceptance of solar energy in the marketplace, reduction of the gap betwen target solar energy costs to achieve market penetration and current cost estimates for solar energy is the essential prerequisite of the scenario. As noted previously, this reduction of the relative price differences between solar energy and competing fossil fuels can be achieved through one or more of at least three general mechanisms: (1) successful solar energy research and development, (2) solar energy subsidies, and (3) taxes on fossil and nuclear energy. Strictly speaking, the third of these alternatives leads to a different demand level for energy. The first of these mechanisms differs from the second and third in the uncertainty of its achievement. Solar energy optimists today generally believe that effective research, development and demonstration of solar energy systems will meet many, most, or all of the required cost targets to achieve a solar emphasis future. Their most convincing argument is that the development of solar energy technology is today only in its infancy, having seen little research emphasis until only recently. Solar energy pessimists are considerably more skeptical about the limiting solar energy costs, generally citing the high cost of materials to collect diffuse sunlight and the intermittent nature of solar insolation.

Recognizing that the achievement of a solar energy future like the solar emphasis case is likely to require some mixture of the three implementation mechanisms stated above, we wish to know the similarities and differences among stakeholder responses to three mechanisms. Consideration of five stakeholder groups provides clarification:

a. ENERGY PRODUCERS AND RESOURCE OWNERS

All three of the mechanisms for achieving the solar emphasis case result in a loss of economic rent to the owners of fossil and (indirectly) nuclear energy resources. The model calculations suggest that this loss could amount to $10 billion annually, a large adverse impact on the energy resource owners and producers. In addition, the fossil energy producers lose markets to solar energy. Although the deregulation of energy prices and accompanying government tax measures can be accomplished in such a way as to reduce these losses, maintaining equity among the energy producers will be a difficult task indeed.

b. SOLAR ENERGY SUPPLIERS

The suppliers of solar energy systems and support industries are unambiguous beneficiaries of the solar emphasis case. These suppliers will undoubtably consist of a mix of new industrial sectors (e.g., the aerospace industry, electrical suppliers, etc.). There is no apparent way to differentiate the impacts of the three implementation mechanisms on the energy suppliers.

c. ENERGY CONSUMERS

A successful R and D program on solar energy reduces energy costs to the consumer. This does not mean that an unlimited solar energy R and D budget produces consumer benefits. Government investments in research and development are a form of subsidy. Only if the investment results in commercial technology does the consumer benefit. A subsidy of solar energy is paid for by the consumer in the form of increased taxes. Similarly, energy taxes on competing fuels are paid for by the consumer. The cost to the consumer of the tax versus the subsidy depends on how much of the tax is returned to the taxpayer as tax credits or in some other form. If no tax compensation is effected, then the consumer pays more for the tax than the subsidy, because the tax is levied against all fuels competing with solar and these constitute the largest part of the energy consumption even in the solar emphasis case.

d. REGIONAL INTERESTS

All three implementation mechanisms for the solar emphasis case favor those regions of the U.S. where solar energy achieves the greatest market penetration. The topic of regional interest groups is of sufficient importance, and has generally been so neglected in the analysis of energy problems, that the next section is devoted to it.

e. ENVIRONMENTAL AND CONSERVATION INTERESTS

Of the three implementation mechanisms, the solar subsidy is clearly the least desirable from the point of view of environmental and conservation interests. The reason for this is that a subsidy reduces energy prices (both solar and, as we have seen, fossil prices) and this encourages growth in the consumption of energy.

4. Regional Interest Groups in the Reference and Solar Emphasis Cases

a. ENERGY PRODUCING REGIONS

In both the reference and solar emphasis cases, the center of gravity of the U.S. energy supply system is shifting to the western regions of the United States. We have until now described this phenomenon in terms of numbers of coal gasification plants, unit trains, coal mines and the like that appear on the western horizon. But this description omits the political and social changes that are certain to accompany the movement of people and capital into the resource regions of the West. A useful perspective on the future of western energy resource development comes from investigating the events that have taken place in two areas, the Gulf Coast states and the Appalachian coal region.

Both regions began with roughly comparable amounts of natural wealth—coal and oil in the ground—but today we see the parts of West Virginia, Kentucky and Pennsylvania with played-out mines as depressed areas, with high poverty, high unemployment, declining industry and population, while most of Texas and the Gulf are booming with growing prosperity, great wealth, and one of the lower unemployment rates in the nation. Part of the contrast between these two areas is the result of different energy policies.

- *Regulation*—The Appalachian coal states allowed largely unlimited development, which resulted in active price competition and cheap coal. After a period of similar cut-throat competition, Texas established controls on the rate of pumping oil through its Railroad and Warehouse Commission. These controls were justified as needed for conservation but for many years the pumping rate was held well below the rate justified by conservation alone. Surrounding states cooperated with Texas and this constraint allowed these states to maintain high oil prices while also increasing the total amount of oil recovered. The coal state policy created more jobs in the short run since their cheap prices meant fast development. West Virginia and the old coal states were of great service to the nation; they subsidized U.S. industrialization, but found themselves comparatively impoverished as new technology shifted to new energy supplies (Mierny, 1976). Texas, on the other hand, is left with great wealth and an extensive industrial base to sustain growth.

- *National Policy*—Texas congressmen played a decisive role in shaping national policy to serve the interests of the Texas oil industry. They helped pass oil tax benefits such as the 27-1/2% depletion allowance and intangible drilling costs. In 1958, when cheap foreign oil threatened the Texas oil price, they helped push through oil import quotas. West Virginia, and the other coal states lacked the imagination and votes to gain comparable Federal largesse.

The future of the existing oil supply regions is not necessarily rosy. Texas and Gulf Coast oil production is likely to decline between now and 2000. The tables will be turned as Texas exhausts her oil reserves while Appalachian coal production doubles.

Since coal syncrude will set the new price limit on Texas crude, it will be very much in the interest of Texas to limit coal development and keep up the price of its closest competitor, western coal. In terms of employment, it is even more important to support the Gulf Coast petro-chemical complex by maintaining access to cheap crude oil—imports could be the long-run answer. As Texas and Gulf Coast exhaust their oil resources, their political outlook will change from that of a net energy exporter to a net energy importer.

The choice for emerging energy supply states is, to a certain extent, the choice between immediate boom and slower development which would delay the ultimate decline. From the perspective of an individual state, a set of energy production policies to maximize benefits to the citizens of that state would include:

- Maximize public ownership of minerals. Keep present publicly held mineral rights, and buy new ones where the price is low. (The University of Texas is supported by its own oil wells.)
- Maximize returns to state residents where mineral rights have already been sold, and place no maximum price on surface rights purchased prior to development. Do not grant power of eminent domain, thus forcing owners of mineral rights to pay much of the value of the minerals to surface owners—ranchers, etc.
- Set taxes on mining (severance taxes) at a high enough rate to slow development but not stop it. A slow rate of development will avoid the social problems of boom and bust development. Charge what the market will bear.
- Use severance tax revenues to cut personal taxes and encourage development of a more desirable, permanent nature. Coal tax revenue could easily be sufficient to end sales and income taxes in states such as Wyoming and Montana.
- Establish consistent policies and taxes with other coal and/or energy producing states to achieve a degree of uniformity on such policies as state severance taxes.
- Use zoning power, health codes, building permits, etc. to prohibit "trailer camps" and require the building of permanent, well-built new towns. In some states this may mean reducing local autonomy and establishing strong regional if not state-wide planning bodies. Require energy development companies to finance most of these public facilities. Again, cooperate with other states and calculate carefully what costs the market will bear.
- In water short states, require energy developers to develop new or outside sources of water. Attempt *not* to sell existing water. Energy developers can easily shift these costs to energy users, and whenever energy development ceases, the State would be left with cheap water. Alternatively, water short energy supply states, energy developers, and energy deficient states could join together to get Federal funds for water from a new source such as the Columbia basin.

Within a new producer state, the majority of the citizens are likely to see potential economic benefits including high wages, more jobs and large capital gains for owners of existing homes, land and other assets. Opponents of the energy development would include individuals greatly concerned about environmental problems, crowding of recreational areas, and changing character of small towns.

Altogether, a managed development schedule, combined with high severance tax should gain support from most all these groups, particularly when connected with reduced personal taxes. Owners of energy resources, who might make lower profits in the meantime under this approach should be the only dissatisfied group.

b. ENERGY CONSUMING REGIONS

All of the energy scenarios imply a fundamental change in the relative wealth of energy-producing and energy-consuming regions. This wealth transfer will take place in two ways: higher energy prices in energy consuming regions and movement of industry, along with jobs, population, and prosperity away from high energy cost regions.

The introduction of solar energy could exacerbate this problem because without special regional subsidies, solar energy for some applications is more costly in the North than in the South. The brunt of this higher energy cost/loss of employment problem is likely to be felt in the Northeast. London (1976) has summarized the current economic problems of the Northeast that are caused by energy matters:

> "Energy prices in the Northeast are often twice as high as in the fast growing South, Southwest and West. Oil costs $2 per million British thermal units (Btus) in New England while contract natural gas, which fuels most industry in other areas costs about $1.30 in the South, $1.06 in the Southwest and $1.13 in the Mountain states. An industry in the Mid-Atlantic region pays $1900 for electricity which costs its competitors $820 in the Tennessee Valley, $785 in the Southwest and $855 in the Rockies....
>
> "As a result of these problems, what growth is taking place in the Northeast is taking place in a limited number of sought after industries, which do not need much energy, which locate in suburban areas where trucks can serve them and which can ignore the local tax situation. Billions could be spent in the Northeast for politically attractive palliatives; urban mass transit, housing, education, public service jobs, and welfare, but if energy, transportation and local tax costs remain noncompetitive sustained demand for workers and capital investment will not be generated in the region.
>
> "High energy, transportation and local tax costs have drawn off funds which might otherwise have been spent to redevelop the Northeast's decaying physical plant. At the same time, Federal programs over the past 40 years have built modern facilities in other regions. $3 billion in Federal investment built over twenty dams and powerplants in the TVA area, secured the area from floods, and provided it with a 650 mile low-cost transportation system. The Bureau of Reclamation, which operates only in 17 western states, has spent over $6 billion since 1970 on capital projects, which make private investment more attractive. $8.7 billion in Corps of Engineers spending since 1960 has been oriented toward the Sunbelt states, and over $79 billion in Federal highway money during the same period has made the wide-open spaces of the west and south more attractive for business investment than eastern city centers."

To the extent that regional discrimination presents a problem in the solar emphasis case, politics and especially Congressional politics will play a major role in attempting to resolve differences. But already it is clear that there are major regional energy problems in addition to those of the Northeast (e.g., natural gas shortages have affected the East Coast severely while gas is burned as boiler fuel in Texas and Louisiana; the oil embargo particularly impacted the Midwest) and that mechanisms have not yet evolved to adequately deal with them.

5. The Low Demand Case

It is not difficult to note direct stakeholders affected by the low demand scenario: owners of energy resources, whose profits are reduced; energy industry, who lose because of reduced long-term growth prospects; energy-intensive industries, whose products become less competitive with substitute products of lower energy intensivity; workers of all sorts, who perceive their employment to be threatened; consumers, who will probably pay higher prices (in spite of tax return); environmental, conservation groups, and others, who profit from improved environmental conditions; all people concerned with rising oil imports and the potential of an embargo; future generations, for whom non-renewable resources are preserved.

This list could be extended, but it soon becomes clear that an adequate stakeholder analysis of the low demand case would be a major undertaking, and perhaps not the best way to illuminate the real issues involved. Part of the reason is that the low demand case represents a major change in society and in the roles of the stakeholders groups. The uncertainty in knowing the directions that these changes might take makes the forecasting of stakeholder responses even less feasible. For example, a worker displaced from a job in the aluminum industry will be deeply affected if he is made unemployable. On the other hand, if he makes a transition to a satisfying job of a different nature from that of his former occupation, his response will be very different.

These arguments suggest that considering only the response of an individual whose immediate self-interest is challenged by a transformation of the status quo is likely to be an inadequate characterization of the longer run response to the low demand case. (It should be useful in sorting out short-term reactions.) Understanding how people will react to fundamental changes in society requires an inquiry into their ideas and perceptions of reality. Many of these perceptions may be expected to transcend a person's role as a wage earner, a father or mother, a member of one or more stakeholder groups. This need to deal with different views of reality in a holistic sense has given rise to the discussion and analysis in Chapter 5, which picks ups and extends the comparison of energy futures.

4. CONCLUSIONS AND POLICY IMPLICATIONS

The effect of an energy policy is not simply the sum of individual impacts. There are no such simple cause-effect relationships. Rather there tends to be what Gunnar Myrdal has called "spiral causality." An action produces an effect that in turn modifies the nature of the action, that in turn...And so on. That is why the scenario is such a useful tool. It is a way of checking whether postulated actions and reactions fit together and make a believable story.

Thus the observations summarized below come not only from the assessments of direct impacts of the preceding chapter, or even from those plus estimates of the "second-order" impacts of those impacts. Even more, they emerge from examination of the scenarios as wholes, attempting to sense not only what events make up the scenarios but what sort of place these scenarios would be to live in.

We shall describe these conclusions and policy implications in the following order. First, there are a number of implications that relate directly to solar energy and these are the focus of the section that follows. Second, we summarize the impacts of the total energy picture and in particular the ramifications of reducing energy growth.

A. IMPLICATIONS FOR SOLAR ENERGY DEVELOPMENT

Solar energy will be meeting increasing portions of the nation's energy needs in the future, but there are a number of obstacles to early market penetration. These two points are summarized in this section as is the special importance that decentralization seems to have when analyzing solar energy policy options.

1. The Long Range Future of Solar Energy

In an area fraught with uncertainties, one conclusion seems sure. That is that energy prices will eventually rise until solar energy is cost competitive with nuclear and fossil energy for many applications. In general, however, solar energy is not yet competitive. This is partially a fact of nature, but it is also the consequence of many other factors including past research priorities, past environmental policies, past economic policies such as price regulation and depletion allowances. Simply stated, it has been easier and cheaper (although perhaps not smarter in the long run) to live off capital (fossil fuels) than income (renewable energy sources).

It turns out that our past energy policies have often used both nearsighted economics and nearsighted social policy. For example, it made excellent short term economic sense when, 25 years ago, financial incentives were offered persons with operative solar water heaters to decommission them in favor of the reliable service of the utility company. One might have questioned the wisdom of this policy from the standpoint of conserving what, surprisingly soon, were to become scarce resources. We made a social decision with the rural electrification policy in the 1930s and encouraged the dismantling of millions of perfectly serviceable windmills and their replacement by electric pumps. Regulation of natural gas prices at a level that encourages rapid depletion of an irreplaceable resource is a more recent example of short-sighted, socially driven economic policy.

One of the most critical factors inhibiting the deployment of solar and other renewable energy sources in the past has been the low price implicitly assigned to nonrenewable resource concentrations in the ground. It was OPEC that publicly acknowledged this in 1973. From the standpoint of the supplier, and using economic logic, the future depletion of these resources can be adequately taken into account by considering in present decision making an appropriately discounted high future price. That is, recognizing that through scarcity the price of these resources will be higher in the future, the supplier decides–discounting the value of this future sale at, say, 15% per year–whether it is advantageous to sell now or wait. The cost of fossil fuels increases as the highest quality and most easily accessible resources are depleted. Even so, a high future price of fossil energy resources, when reflected back to the present with typical discount rates, has little value in the present. Thus, even though some of the future scarcity of energy resources enters present decision making, the interests of future generations hardly enter the picture.

Even the basic concept of discounting is questionable when applied to irreplaceable resources. Discounting future benefits to the present is a rational process for an individual. Money obtained today can be invested and made to be worth more in the future, so an individual is likely to have a preference for a benefit today rather than an equal benefit in ten years. However, the concept of discounting is a questionable one if applied across generations. Discounting is applicable to long-range societal decisions in two instances:

1. If the decision will improve the welfare of future generations, or

2. If future generations will be substantially better off than the present generation so that transferring resources from the future to the present improves the equality of welfare.

The latter assumption has been implicit in our planning during the past 200 years of American history, but in the case of energy use, future generations may in fact be poorer in energy than our generation.

The effect of this domination of both economic and social decision making by interests of the present generation has been that exploitation of fossil fuels has been economically preferred over development of renewable energy sources. A higher price assigned to fossil resources in the earth (on the grounds of their irreplaceability for future generations) would have the effect of husbanding nonrenewable resources and stimulating development of renewable energy sources. The recently imposed severance tax on coal by the State of Montana is a step in this direction.

World fossil energy resources could be essentially exhausted within the next century if past growth rates of consumption continue. (Coal would last for centuries only if the rate of consumption did not grow.) It is problematic to expect nuclear sources to replace the fossil fuels completely because of unresolved technical problems and uncertain acceptability to the public. Even should the fast breeder and/or fusion become technically and socially feasible, these processes could have siting and waste heat problems that impose limitations on their supply capabilities.

Thus, even if nuclear power eventually becomes technically successful, economically attractive, and accepted by the society—and especially if it does not—solar energy will be needed for supplying a significant fraction of the nation's total energy requirements in the future. (See, for example, Figure 4-1).

Because fundamental shifts in the energy system can take so long and can have such a large impact, the anticipation of a major transition to solar energy sources has important implications for national policy options. The knowledge that 50 years in the future we will be utilizing a significantly different energy system (whether solar, nuclear, or whatever) is important to present choices of federal policy on land use, population distribution, public transit, research and development priorities, air quality standards, depletion rates for fossil fuel resources; it relates indirectly to policy choices in such areas as economic growth, full employment, the U.S. world role, the centralization of governmental power, and long-term goals. Energy decisions made today will shape the options in these areas in the future, and choices in these areas will affect, in turn, energy options available 50 years from now.

Decisions on major societal issues are, in a free-enterprise democratic society, diffused throughout the structure. The overall choice of society is actually the

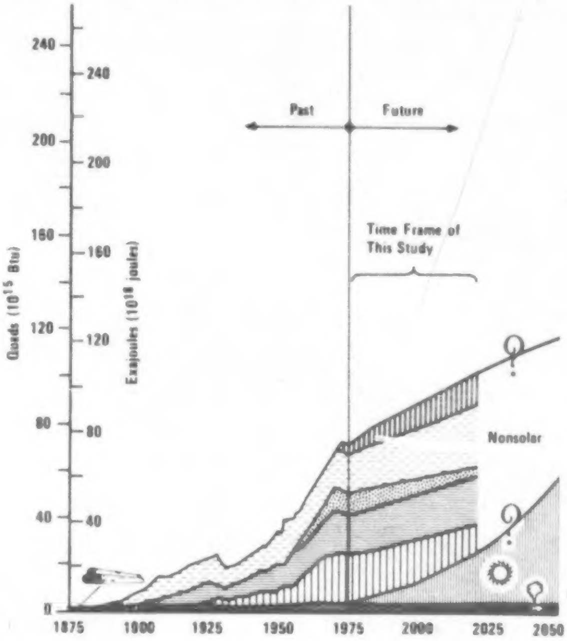

Figure 4-1 Energy Supply Uncertainties Beyond 2020

composite of a vast number of choices made in various governmental agencies, in the private sector, among public interest groups, the citizenry. It is evident that society's decision with regard to its energy future is inevitably a part of a broad societal choice involving far more than the selection of energy technologies.

The federal role in influencing energy choices and related major societal decisions can be viewed as that of adjusting taxes, legislation, and other incentives to guide private investment to accomplish these societal ends.

In summary: It is clear that solar energy will have a vital role to play in the future. There are obvious advantages to beginning its development in advance of the time it may be desperately needed. This argument is not new. We frequently hear it today in regard to nuclear power. It is essential that the social decision to deploy solar or any other new technology be made on the basis of economics that reflect social criteria. The solar decision should be part of a broad societal choice of a total desired future.

2. Implementation Problems and Impacts of Solar Energy

Even though ultimate large-scale use of solar energy is likely, substantial efforts will be required to realize a large solar market share during the next half century.

The principal implementation problem for solar energy is reducing the relative costs of solar systems so that businesses and individual consumers are willing to use solar energy systems. The magnitude of these implementation problems depends on the degree to which relative solar costs are reduced by successful R&D.

If solar R&D is successful in reducing the true economic costs of solar energy below the costs of nonsolar energy sources, there still remain other implementation problems. The primary problems would be in changing federal energy policy. Even with successful solar R&D, if solar is to be competititve the federal government must move away from policies which hold down the price of existing resources. The following federal policies would have to be eliminated:

- Depletion allowances for oil and coal
- Price ceilings on oil
- Price ceilings on natural gas
- Other tax benefits for fossil resources
- Subsidies for nuclear power, including federal insurance, low-cost uranium enrichment, and low-cost fuel reprocessing, and low-cost waste storage.
- Low-cost federal power from TVA, Bonneville, REA and other federally aided electric power systems.
- Tax exemption for bonds that finance public utility systems.

In the heating area, where solar R&D is likely to achieve competitive solar costs most quickly, further implementation measures would be necessary. The principal barrier to market penetration of solar heating tends to be institutional. Whereas industry can move quickly whenever there is economic incentive, residential systems are more sluggish for a number of reasons, including:

- Rigidity of building codes
- Slow housing replacement rate and low incentive to retrofit
- Rapid turnover of home ownership (average ownership period 5 or 6 years) and uncertainty about the value the new owners will place on solar equipment
- Hardship on homeowners because of high interest rates and high front end costs.

Solving these problems could require a federal role in local building codes and new residential financing.

If solar R&D does not achieve dramatic reductions in relative solar costs, then there are only two policy options for achieving substantial solar energy use. These are direct subsidy and increasing the costs of nonsolar energy sources, and these policies are required in addition to the ones already discussed.

If the baseline solar costs are accurate, direct subsidy to produce a 45-quad solar market share by 2020 would cost between $20 billion and $30 billion per year (beginning in 1990 when the solar electric technologies are assumed to be commercially available). Such a subsidy would be a somewhat better bargain for society than might appear at first thought. One of its effects, while reducing the cost of solar energy to the users, would be also to reduce the overall price of electricity and heat. (Less energy will be required from other sources, so the price goes down.) Thus, citizens as taxpayers would pay the subsidy, but many of the same citizens might receive some of this back in their lowered bills.

Such a subsidy would have an unfortunate side effect, however. The lowered energy price would encourage more energy use—thus working against energy conservation efforts. An alternative policy is preferable from this standpoint. A tax on competing forms of energy would achieve the same objective of making solar energy cost-competitive, and at the same time would encourage energy conservation. Of course, an energy tax would have a depressing effect on the economy—unless other taxes were lowered to compensate, or the government spent the extra income increment to generate jobs to combat the unemployment presumably caused by the raised energy prices.

Obviously the issue of promoting solar energy supply cannot be considered in isolation. It interacts intimately with a number of other economic and social issues. The political difficulties of implementing solar energy would be substantial, but the solar implementation problems may appear relatively modest when compared to the implementation problems of nonsolar energy futures.

Once a move to solar energy is implemented, the remaining impacts are relatively small. Solar energy causes little or no air or water pollution and the largest solar use—heating—requires little land. Solar material requirements are well within U.S. production capacities.

However, some solar uses require large amounts of land. Centralized solar electric power—either solar-thermal or photovoltaic—requires 7 to 15 square miles of land for a 1000 MW(e) plant. With competition for land for community development, agriculture, forestry, recreation, and wilderness preservation, obtaining such large tracts of land (especially east of the Mississippi River) will be a severe problem. To deal with the intermittent nature of solar energy it will probably be desirable to develop solar-thermal central stations in conjunction with hydroelectric plants, hydro storage, or coal fired plants where feasible. This consideration would further restrict available sites.

Plantation production of biomass would also require large amounts of land. Plantation biomass directly competes with agricultural production because it is not feasible in desert areas. However, we estimate that 5 to 7 quads of biomass would be available from agricultural and municipal wastes. Biomass has a land problem only beyond this level of use.

In summary: Solar energy is not a cure all. It is on the whole environmentally and socially benign compared with other energy technolgies. Although some solar heating systems are now or will be cost- competitive soon, other solar technologies are expensive. Solar deployment would require controversial changes in federal energy policy. If solar R&D does not achieve cost breakthroughs, substantial solar subsidy or nonsolar energy taxes would be necessary to reach ERDA-49 goals.

3. The Potential of Decentralized Solar Energy Systems

There are a number of reasons the nation might choose to encourage development of decentralized solar energy: (1) a potential increase in the fraction of U.S. energy supplied from the sun; (2) decreased vulnerability of the U.S. energy system to disruption; (3) responsiveness to the desires of some to use energy decentralization as a force toward more general decentralization; and (4) responsiveness to the needs of developing countries for whom small solar technology is most appropriate.

Development of decentralized solar energy systems could enhance the ability to supply a significant fraction of U.S. energy needs from the sun. Many energy needs are inherently dispersed, and hence they can be effectively met by dispersed energy systems (e.g., many rural power requirements; remote irrigation pumps; isolated communication stations). Decentralized solar systems can mitigate the problems associated with the necessary large collection areas by making more effective use of such unused spaces as rooftops, parking lots, mass transit corridors, and utility easements.

Centralized systems are vulnerable to man-made (e.g., terrorism and sabotage) and natural (e.g., hurricanes, floods) disruptions. In fact in the case of terrorism, the centralization itself makes a more attractive target—to sabotage one nuclear power plant is more appealing to a terrorist group than the prospect of damaging a million solar water heaters. For maximum reliability and economy, an energy supply system should probably contain a mix of centralized and decentralized processes. The decentralized portion might well consist of wind, photovoltaic, and small thermal generators (e.g., rooftop collectors furnishing energy to a freon-driven engine-generator), all serving local loads or feeding surplus power into the grid. Ownership might rest with householders or with the connecting utility companies.

From another vantage point, some citizens have expressed a desire to be more energy self-sufficient, and to own and control their own decentralized solar energy systems—and to have them connected to the utility company system for backup. Thus far both the capital requirements and the attitudes of the utilities have opposed this. However, under certain conditions the utilities might find it operationally and economically attractive. The expressed desire will no doubt bring some pressure for increased federal emphasis on development of decentralized solar technology.

Complex, large-scale energy systems are not appropriate to many of the needs of developing countries. They are too expensive to build, energy demands do not justify them, and they can contribute to reduced self reliance. Whereas it is not possible, for example, to provide small, simple nuclear reactors for Third-world villages, there are a variety of appropriate small solar technologies that could be extremely useful (e.g., water pumps, cookers, water heaters). Were the United States to use its technological and mass production capabilities to develop and market these items it could provide the nation continuing economic, political, and technical advantages in the world community.

Pollard (1976), after examining the technical and economic problems associated with centralized solar energy, summarizes:

> It should be evident from this analysis that the direct use of the sun is simply not a very suitable way to provide electricity in utility systems designed to supply it on demand...None of (this dubiousness)...is intended to apply directly to rural areas in the United States and developing countries or to remote places in the world. Small, self-contained total energy systems using local wastes to supplement solar heat, combined with wind or photoelectric generation and limited storage and no transmission costs, seem destined to play an increasingly important role in the total world energy system. There are attractive possibilities in such applications, and their economic and practical evaluation rests on quite different criteria from those for central station power.

In summary: The future potentialities of decentralized solar energy deserve more emphasis than they have received thus far.

B. SOLAR ENERGY IN THE CONTEXT OF THE TOTAL U. S. ENERGY SYSTEM

When solar energy is examined within the context of the total U.S. energy system, the impacts associated with high levels of energy consumption come into focus, and this leads to questions regarding the costs of moving to lowered energy growth rates. The fact that energy policy analysts are seriously examining energy projections over the next 25 years that differ by a factor of 2 or more is an indicator of major uncertainties that exist with regard to future energy demand. We summarize our results regarding these points in the remainder of this chapter.

1. Costs and Impacts of High Energy Demands

The most impressive fact that emerges from examination of the half-century reference scenario—with or without solar emphasis—is the extremely high cost to the society in social and environmental terms. All scenarios supplying over 100 quads per year after the end of the century are necessarily dominated by coal; there is no other immediately accessible source in sufficient quantity. Providing sufficient western coal to actualize the reference scenario (of the order of four billion tons annually compared with the present 130 million tons annually) involves severe local environmental disruption. In addition, it poses the potentiality of conflict between the coal-producing states and the rest of the states, both over coal price and over rate of development.

Both the reference and solar emphasis scenarios also require substantial amounts of nuclear power. Finding sites for several hundred nuclear power plants and implementing the advanced nuclear technologies are likely to be accompanied by enormous political conflict.

A partial listing of the implementation measures that were required to make the two high growth scenarios plausible will suffice to illustrate the potential for interest-group conflict:

- Subsidies for and measures to facilitate rapid construction of boom towns in the coal-producing areas.
- Relaxation of nondegradation air quality standards.

- Adoption of " reasonable" standards for reclamation of western stripmined lands that will not be impracticable to meet—probably significantly short of full restoration because of water limitations.

- Suspension of air-quality standards for selected minemouth conversion plants.

- Arrangements for disposal of shale oil residues on private or public lands (unless in-site processes are commercialized).

- Measures to limit nuclear plant siting delays.

- Establishing "socially acceptable" means of high-level radiation waste storage.

- Establishing international control of nuclear material.

- Actualizing a satisfactory plutonium recycling system.

- Subsidy (or the equivalent) in the solar emphasis scenario to develop solar energy, aiding primarily the southern half of the country.

Such necessary implementation steps will inevitably hurt some stakeholder groups, and will involve social issues that far transcend specificaily energy supply issues. Political will to implement an over-100-quad scenario will be difficult to arrange, in general, although the specific decisions to be made may vary from one scenario to the other.

In spite of talk about "energy independence," domestic crude oil production will soon peak and nuclear supply is likely to fall short of original goals. In general, requirements for imported oil will increase, not decrease, for moderate demand and high- demand scenarios. The political and economic costs of this are heavy, and it seems that solar energy does not significantly change this dependence on foreign energy sources.

In addition, solar energy use does not dramatically alter consumption of fossil resources. As Figure 4-2 shows, the cumulative fossil resources used between now and 2020 differs by less than 10% between the reference and solar emphasis cases. The low demand case, in contrast, reduces cumulative fossil resource use by over 35%.

In summary: Implementation of anything close to a historical energy growth rate scenario with or without solar emphasis will be extremely costly to the society economically, environmentally, and in terms of the necessary implementation measures.

2. The Potential for Lowering Growth in Energy Consumption

The preceeding chapter suggests that there are many adverse invironmental, economic, and social problems associated with the increasing consumption of primary energy resources. However, there are many ways to reduce the growth of energy resource comsumption without reducing the net energy services to society. In almost all cases, such measures reduce adverse environmental and social problems of energy supply while causing little or no new environmental and social problems. We have found it helpful to classify these measures into three groups: *conserving, cascading,* and *curtailing.*

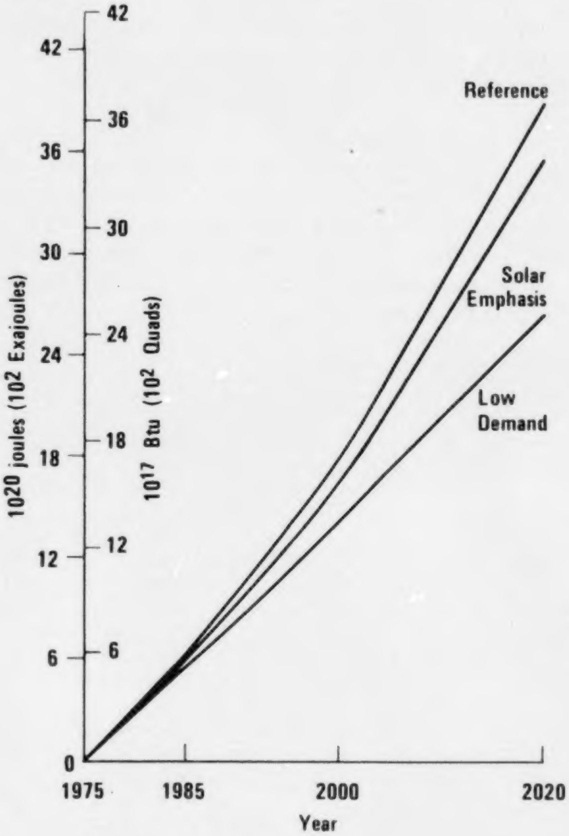

Figure 4-2 Cumulative Fossil Fuels Used

By *conserving* we mean energy-conserving measures such as those that provide the same level of energy service while requiring less useful input energy. That is to say, energy-conserving measures generally provide the same energy output with a smaller energy input. These measures impact the quantity of energy used so they can be considered to be manifestations of the First Law of Thermodynamics. Generally, energy-conserving measures involve the substitution of capital to reduce the need for energy. For example, adding insulation to a home or installing a more efficient furnace results in a lowering of energy consumption while the level of service (a room heated to 68°) stays the same. Other examples are installing radial tires on cars, putting more insulation in industrial heat process equipment, designing new high-bypass fanjet engines or airliners, and so forth.

The rationale for *cascading* invokes the Second Law, dealing with the ability of energy to do mechanical work. This is less well understood. When energy is sold at so much per Btu or kWh, the consumer is inclined to miss the significance of *how* that energy is used. A high-efficiency power plant may convert three units of fuel energy into, roughly, two units of waste heat, useful for only a few purposes such as space heating, plus one unit of electrical energy. This electricity is far more versatile than the original fuel; it can do more mechanical work than the same amount of heat energy. But unless this extra quality is used to advantage, the process is wasteful. Cascading and matching refer to ways to avoid using energy of a quality much higher than actually required.

Examples of cascading are:

Using waste heat from processes requiring high quality (high temperature) energy (e.g., a steam turbogenerator) to supply low-quality uses (e.g., space heat, low-temperature process steam).

Avoiding the use of high-quality energy (e.g. electricity) for low-quality uses (e.g., space heating in homes). The use of a heat pump to obtain heat from the invironment is consistent with concepts of cascading.

Using renewable sources where possible (e.g., solar heat for agricultural drying and industrial process heat; using agricultural, forestry, and urban waste to produce methanol or methane, or as fuel).

As with conserving, cascading implies virtually *no* perceived differences in energy services provided. A house heated with a heat pump feels just as warm as one heated with resistance heat, yet it requires half the energy.

Curtailing energy use implies a *change* in energy service that, in some cases, could be interpreted as a loss of amenity. However, many energy curtailments do not necessarily represent sacrifices:

Using carpools to reduce commuter vehicle miles.

Consumer energy saving (turning off light, reducing heat).

Substituting for high-energy-content materials (e.g., aluminum).

Shifting activities to daylight hours, using sunlight for illumination, reducing demands for power in the evening hours.

Substituting local recreation for vacation travel.

Substituting rail travel for air and alutomobile travel.

Repair, re-use, resist replacing with a later model present automobiles, appliances, etc.

Increasing load factor on airplanes by accepting the inconvenience of full planes and less frequent schedules.

Current estimates on the quantity of energy savings that could result from such measures run as high as 30% of projected energy demand in 1990. This is equivalent to a much slower growth in energy use during that period. Cultural changes that affect consumption and work patterns could reduce energy demand still further. In the discussion of the low demand scenario, the consequence of this on reduced impacts was examined.

Thus we conclude that: Reduction in quantity of primary energy consumed tends to be far more significant in reducing adverse environmental, economic, and social impacts of energy consumption than are changes in type of energy technology or source.

3. Uncertainty and the Importance of Future Attitudes

The policy decisions relating to energy development in general and to solar energy development in particular are surrounded by an extraordinarily high degree of uncertainty. This is evidenced, for example, in the widely varying projections of the energy that the nation will demand by the end of the century- projections running all the way from under 100 quads per year to over twice that amount. Furthermore, it is characteristic of this uncertainty that it relates as much to future attitudes, values, and perceptions as to physical constraints.

It should not come as a surprise that such uncertainty might reside in the sociocultural context. Time and again in recent years careful forecasts made with the best quantitative data have been confounded by unexpected changes in these "soft" variables. Examples include changes in attitude with respect to:

- *Family size,* unexpectedly bringing U.S. population growth below replacement fertility rates in the mid-1970s.
- *Environmental quality,* that, reflected in legislation and public actions, delayed large construction projects and hence affected both energy supply anticipations and economic forecasts.
- *Desirability of urban/suburban life,* resulting in a net out-migration from the urban areas for the first time this century, contrary to demographic forecasts.
- *Science and technology,* resulting in major departures from past trends in federal funding of basic research and introducing a significant perturbation in all post-SST technology forecasts.
- *U.S. world actions and responsibilities,* resulting in the halting of the Vietnam War and a drastic change in the conditions under which the United States might mount any future overseas military action;
- *Consumer rights* with regard to safety of products, misleading advertising, etc., affecting business forecasts;
- *Reasonable returns* in wages, interest, court awards in tort cases, etc., contributing to inflation, shortage of investment capital, and a precarious business environment.

Thus, market penetration of solar residential heating and cooling, for example, is a function of future attitudes as well as of costs. Rapid development of solar thermal electric power depends on attitudes toward land use, environment, and utility companies as well as on economic factors. Rate of solar technology development is a function of public attitudes affecting Congressional actions and funding priorities. Costs of competing forms of energy (e.g., nuclear energy, imported oil) depend critically on attitudes both within and outside the United States. The amount and form of energy use will be affected by value emphases and choice of life styles.

Forecasts of energy supply and demand, anticipated effects of energy-conservation and environmental- protection measures, and efficacy of energy and environmental policy all would be affected by attitudinal shifts in the future. Examples include changes in attitude with regard to:

- *Economic growth* and energy-use growth vs. the social and environmental costs accompanying both.
- *Regional environmental degradation* to meet the energy and materials needs of other regions (e.g., land, air, water pollution associated with shale, coal synthetics).
- *Holding to environmental standards* embodied in the Clear Air and Water Pollution Control Acts vs. the economic hardships on business of doing so.
- *Economic incentives for industry* to develop needed energy sources (e.g., price guarantees for shale oil and coal synthetics, incentives for private sector exploration for offshore oil—in a climate of greatly increased distrust of big business).
- *Personal savings* and hence availability of capital.
- *Population distribution* (e.g., small cities taking measures to limit population growth).
- *Distribution and use of limited resources* (e.g., choice of using Western water for agricultural purposes or energy developments).
- *Wild life* (e.g., attitudes toward endangered species, interfering with natural migration paths, disrupting critical winter nesting areas).

- *Health hazards* (e.g., fear of carcinogenic agents on the one hand, or on the other hand acceptance of hazards to keep the economy moving).

- *Dietary customs* (e.g., continuing to consume energy intensive meat and processed foods).

- *Voluntary frugality* such as simplifying life style to require much less materials, travel, energy, etc.

- *Distribution of the earth's resources,* especially as between rich and poor nations.

Attitudes of populations in other nations are important as well. One obvious example is the expectations, aspirations, and resentments of poor and largely nonwhite nations. Another is the attitudes of oil-rich Middle East nations toward shared political objectives, and toward careful husbanding of their underground treasure.

Important as values, attitudes and preferred life styles obviously are, and in spite of recent indications that they may be shifting ways of treating the resulting uncertainty in policy analyses have not received much attention until recently. The following chapter deals with these sources of uncertainty, and with the consequent implications for policy.

5. THE BROADER ISSUES

The preceding chapter summarized the main policy implications that emerge from the analysis of energy costs and energy demand levels in Chapter 2 and from the impact analysis in Chapter 3. However, that analysis yields only a partial picture of the energy policy issues involved. Because energy has such a major role and creates so many impacts in industrialized society, energy issues cannot be probed seriously without uncovering the web of national and global issues with which they interweave.

From the scenarios developed in Chapter 3 it is also clear that different stakeholder groups weight their prospective gains and losses very differently, and that multiple tradeoffs are involved. But these interest-group conflicts only hint at the much deeper differences in the very *perceptual frameworks* through which various observers view the nation's energy options and their relationship to the economy and to societal well-being.

In this chapter we explore some of these broader issues and the perplexing way in which they take their form in the eye of the beholder.

A. ENERGY INTERRELATIONSHIPS WITH BROADER SOCIETAL ISSUES

To explore more fully the implications of the scenarios, we found it useful to elicit the most significant broad sociopolitical issue areas to which these impacts relate. We accomplished this through what amounted to a much simplified form of factor analysis of the many diverse impacts and of the diverse reactions to those impacts reported in the literature. The following six issue areas emerge clearly:

1. National and global responsibilities.
2. Tradeoffs determining the socially desirable level of economic activity.
3. Needs for and costs of government regulation.
4. Centralization vs. decentralization.
5. Predominant societal goals.
6. Rationality governing decision making.

A brief discussion of each of these follows:

1. National and Global Responsibilities

Energy has obviously become a principal factor in the U.S. role in world affairs. The price of energy affects relative currency values and flows of money. The geographic distribution of energy resources affects the strategic balance of power. The use of energy provides trading goods, transportation, communication, and military power. The different energy technologies and the levels of energy use in the United States directly affect conditions in the rest of the world.

Adequate energy supply is essential to providing a strong economy and a secure defense. It is needed to ensure food supplies for domestic use, export, and foreign aid. It is required to enable the United States to play a vital role in maintaining stability in the world.

On the other hand, the propriety in terms of world responsibility of the disproportionate amount of world resources used by the United States has been questioned. This imbalance is summarized by the oft-quoted statistic that the U.S. with 6% of the world's population uses over 30% of the energy consumed and a similar fraction of other resources.

It may be true that such disparities between centers of wealth and power and outlying regions have been the rule since the first cities appeared in the Middle East and Asia. Nevertheless, such a disproportionate distribution of wealth and energy use may not be consistent with the hopes of the less developed nations for rapid economic development. The United States has long taken the position that through continued technological and economic growth, and with an appropriate amount of aid from the richer nations, the poor nations' pleas for more equitable distribution of the Earth's resources will finally be met. But as we saw in Figure 1-8, a United States per capita use of 2 million Btu (per day) of energy in the resource-limited world of 2020 may not be consistent with a closing of the rich-poor gap. (Mesarovich and Pestel, 1976). Demand in the United Nations and UNCTAD for a "new international economic order" are a direct challenge to the theory that continued economic growth in the rich nations will automatically "trickle down" to the poorer nations and, thereby, improve their lot.

These demands have elicited a good deal of support and empathy within the richer nations as well. There is growing awareness of the justification for what Harlan Cleveland has called a "fairness revolution"–reduced resource consumption by the rich nations and a stronger hand to the developing nations that seek to better their situation. The rich nations are concerned, not only from considerations of equity, but also because of self-interest due to the increasing ability of dissatisfied groups to inflict damage on complexly interconnected, highly industrialized societies such as the United States.

For several reasons it would be advantageous from the standpoints of both the overall resource picture and of world image for the United States to supply a significant fraction of its energy demands in the next century from solar technology. The use of solar energy would result in a lowered dependence on global reserves of oil and would extend limited domestic fossil and nuclear fuel supplies; it would also free those fuels for use in other areas of the world or by future generations and would help to keep world energy prices down. In general, one nation's use of solar energy is not a debit to either other nations or our progeny and, presumably, would be judged favorably in a potentially energy-limited world.

Furthermore, development of solar energy technologies for export and foreign aid is particularly advantageous. Sun-based energy supply is ideally suited to the perceived needs of the poorer, resource-limited nations. Many solar technologies are less complex and more easily adopted by such groups than other energy technologies. Furthermore, solar energy use can contribute to self-reliance in a way that fossil fuel and nuclear technologies frequently cannot. Cheap solar cookers, for example, could lessen a worldwide problem of rapidly growing seriousness; in certain areas of the world there is no more firewood and everything combustible–from shrubs to grass to dung–is burned for fuel instead of returned as humus to the ground, with consequent soil erosion and destruction (Eckholm, 1976).

Finally, the environmental benefits of solar energy might be even more important in heavily populated, developing countries than in the United States. Environmental impacts of conventional energy processes have been difficult and expensive to control even in the lightly populated United States. In countries of much higher population density, it would be even more difficult and costly to control these environmental impacts as per capita energy consumption increases, due to the combined pressures of dense and increasing population and growing energy use. In these situations, energy systems, such as solar, that inherently have low environmental degradation could become very attractive.

Both in terms of responsible national self-interest and of responsibilities to the world community, an argument can be made for the United States to move toward lowered growth of per capita energy use and to derive an increasing percentage of its energy use from renewable sources.

2. Tradeoffs Determining the Socially Desirable Level of Economic Activity

The basic issue here is the balance between benefits (e.g., material standard of living) and costs (e.g., resource depletion and environmental impacts) associated with various levels of economic growth. This issue has several important aspects:

- The relationship between economic growth and resource usage, particularly energy.
- The costs associated with energy and resource supply.
- The costs associated with energy consumption.
- The costs associated with lowering the growth rate of energy consumption below that of the recent past.

The growth of energy assumed in our reference case (200 quads in 2020) is typical of current projections of the energy required to maintain a steadily rising standard of living and acceptably low levels of unemployment. Whether the historical correlation between economic growth and energy use growth will obtain in the future is not clear. One oversimplified argument often heard is that future energy need for a given GNP will be reduced because economic activity is shifting into the low-energy services sector. An equally simplified argument pointing to a contradictory conclusion rests on the fact that personal disposable income tends to be a relatively fixed fraction of GNP, and, thus, the proportionality between GNP and energy use is unlikely to change much without a change in what people spend their income for–that is, without a change in lifestyle. But the simple fact is that we do not know the future relationship between energy use and GNP, nor even the constraints and limits on this relationship–partly because until very recently the question wasn't seriously asked.

We saw from Chapter 3 that the costs incurred in supplying the projected energy demand of the reference case and solar emphasis scenarios include:

- Consumption of foreign crude oil and petroleum products.
- Impending depletion of domestic oil and natural gas.
- Increasing levels of environmental and social impacts from use of fossil and nuclear fuels, even if solar energy is developed with maximum feasible haste.
- Some strains on the capital markets associated with the capital demands of large energy projects.
- Government (i.e., taxpayer) subsidy of industry's developmental costs and venture capital risk protection.
- Social tensions resulting from these environmental and economic impacts; attempts to obstruct energy supply developments; reactions against retreats on environmental protection as these are necessary to ensure adequate energy supply; increasing distrust of both business and government.
- Conflict between federal and state governments over differing priorities and required sacrifices to meet energy demands.
- Conflicts over water rights and land use.

These are costs associated with energy *supply*. They are sharply reduced in the low demand scenario. So, too, are the costs associated with energy *consumption*. When energy and fossil feedstocks are used in industry or transportation, or incorporated in materials and products (e.g., plastics, aluminum, concrete, pesticides, detergents) there tend to be impacts on the environment and natural ecosystems from discarded waste, heat, toxic substances, the supply of accompanying resources (e.g., water, ore, lumber), and other aspects of the economic activity (Commoner, 1971; Georgescu-Roegen, 1975).

These social and environmental costs of both supply and consumption functions suggest the desirability of limiting economic activity and adopting a husbanding approach toward resources, land, and ecosystems, much as a responsible, landed family adopts toward its estate over many generations. Such a voluntarily frugal society has been proposed (for example, in Schumacher, 1973). In general such a society would support the following actions:

- Pervasive energy conservation, curtailment of unnecessary energy expenditure, use of waste heat and cascading of energy sources (total energy systems).
- Gradual redesign of the production and distribution systems toward energy-frugal technologies, more durable and repairable goods, less packaging, reduced transportation between origin of goods and final user, lowered energy-intensiveness of materials, goods, and services.
- Changed agricultural methods to be less dependent on fossil fuels and fossil-based fertilizers; dispersal of farming to place produce closer to consumers.
- Gradual redesign of communities to be more self-sufficient and more congenial to the natural environment and ecosystems, and redesign of work-home relationships to require less transportation.
- Changed incentive structure in the economy to support the above and to ensure equitability of sacrifices and gains.

Such a society would entail lowered environmental and social impacts of resource usage, and would more adequately take into account longer-term considerations relating to resource usage, including the needs of future generations. In addition, it would meet with approval from much of the rest of the world. However, balanced against these advantages must be placed cautions such as the following:

- Present patterns of supplying and using energy and resources have brought a very high material standard of living to Americans, and this should not be put in jeopardy lightly.
- Conservation, energy cascading, curtailing unnecessary energy consumption, and adjusting economic incentives to encourage all of these, are clearly good policy; however, a problem could arise if a frugality campaign were to result in conditions (e.g., a sudden drop in consumer expenditures) that weakened the economy's ability to achieve social objectives, to

compete in world markets, and to maintain a high level of employment.

- Risking the strength of the economy may be unjustified, if there is no demonstrated technical barrier, given the requisite political will, to sustaining present energy use patterns. This viewpoint requires that technological developments be assumed in such areas as solar energy, breeder reactors, and fusion.
- The hazard of reduced defense capability as a result of a weakened economy cannot be ignored.
- If sacrifice is required in the process of husbanding resources, it will be difficult to ensure that this sacrifice is distributed equitably; in addition, there may be adverse social impacts of rationing, price controls, and other emergency measures (e.g., generation of a black market).

As we will see in the next section, this situation of complex tradeoffs, in which key data uncertainties remain unresolved because of research yet undone, is further complicated by basic uncertainties about what the patterns of data mean.

3. Needs for and Costs of Governmental Regulation

As advanced, technology-oriented societies grow more complex the apparent need for governmental regulation mounts. Yet the price of increased regulation is high—in terms of interferences with the functioning of the market economy, bureaucratic inefficiencies, and threats to civil rights and liberties. Because the increasing complexity of the society is intimately related to its use of energy, as energy use rises the call for more regulation tends to rise with it.

A number of energy-related developments have been generating pressure for more regulation of the economy, including:

- Progressive degradation of the environment and endangering of planetary life-support systems by the waste products of industrialized society, including those associated with energy supply and use.
- Amenity, ecological, health, and aesthetic impacts of large energy-and resource-related projects (e.g., strip mines, oil spills, nuclear waste).
- Need to take anticipatory actions regarding resource depletion (in advance of market-response price increases)—especially in the case of fuels, minerals, water, and arable land.
- Need to exercise governmental control over supply and use of energy for reasons of international relations and defense (e.g., to limit oil imports).
- Increasing vulnerability to sabotage and terrorism, particularly if the society elects to move to a "plutonium economy."
- High rate of introduction of new synthetic chemicals whose long-term effect on man and his environment may not be known for decades.
- Aggravated distrust of big business, and increasing doubt that the economic criteria of business decision making are leading the society to good social choices.

Specific remedial actions have often yielded unanticipated side effects—bringing demands for still more regulation. It has become more and more difficult to reflect public costs and benefits into private decision making. Internalizing the externalities (e.g., implementing the "polluter pays" principle) has proven to be a much more formidable task than was anticipated.

Business demands a stable economic environment to keep risks within acceptable bounds. But increasing pressures from the electorate because of deteriorating tradeoffs can lead to erratic fluctuations (e.g., pressure to shift from coal to oil—followed a few years later by pressure to shift from oil back to coal). If the demands for more regulation can be expected to increase further, if the political response to these can be expected to remain erratic, and if the climate toward business continues hostile, the result could be a serious crippling of the economy.

Energy choices also affect the need to regulate in areas other than the economy. The federal government will experience pressure to intervene in interregional conflicts involving the rights of state, local, and tribal governments (e.g., the nation's need for energy vs. Western states' preference for slower development or coastal resistance to offshore oil development).

There will be demands for probes into the internal affairs of private firms (as with the oil companies at the time of the oil embargo). Need will grow for restricting the actions and verifying the loyalty and trustworthiness of individuals (e.g., the safeguards under consideration by the Nuclear Regulatory Commission for policing plutonium) (Ayres, 1975).

All of these pressures would be directly relieved by any amount of reduction of national energy demand, or substitution of solar energy for less benign technologies.

4. Centralization vs. Decentralization

Over most of this nation's history there has been a clear trend toward increasing centralization of productive activity—from the household and cottage industry to the production line and multinational corporation. Similarly, the overall movement in government has been toward increasing concentration of power in the federal government. Demographically, the trend has been toward increasing centralization of population distribution (urbanization). Regional differences in culture have tended to disappear and the influence of the centralized news and entertainment media toward homogenized culture has grown stronger. Energy supply, transportation, retailing, communications, agriculture, and housing all show the same bent. The overall centralizing tendency has been so pervasive and enduring that a trend reversal may seem most unlikely.

Yet there have been many dissenting voices. Thomas Jefferson warned against deruralization tendencies; Justice Brandeis argued "the curse of bigness" in business (1934). Max Weber, who first articulated the theory underlying bureaucracy, was among the first to warn against it. The mood against centralization appears to have strengthened in recent years, and a lively literature appeared. This literature promotes a society "based on a multiplicity of locally autonomous political and economic decision making units (communities and workplaces), popular participation in these units, mutual aid and sharing, relative self-sufficiency within regional ecosystems, and interconnection of local units in federations and cooperatives" (Livingston, 1976). (See Kropotkin, 1975; LeGuin, 1974; Morris and Hess, 1975; Stein, 1974; Stein and Hodax, 1975; Bookchin, 1971; Yates, 1973.)

Most significant is the possiblity of a decentalization trend in the economy, where there has been a centralization trend of longstanding. This centralization tendency has been correlated with increasing energy use (accompanying decreasing energy prices) and increasing economies of scale. For example, the transportation requirements of our present industrial system were designed around low energy costs. The energy consumption demands were designed to benefit from large quantities of inexpensive power from 1000 MW(e) and larger power plants. It is natural to expect that as energy costs increase the industrial system will move to reduce transportation and process energy requirements. This would encourage, for example, more decentralization of electric power generation to facilitate waste heat utilization. It might also encourage decentralization of manufacturing to reduce transportation costs.

It may seem unlikely that such a persistent trend as this centralization tendency would reverse. However, Burns (1976) argues that the relative importance of the household economy *vis a vis* the market economy, which had been decreasing since the early 1800s is now increasing. The household economy is far from negligible. Were its exchanges counted as exchanges in the market economy (e.g., in the GNP), the household economy would be about one-third the size of the market economy. Household structures and durables represent more tangible national wealth than all market economy structures, durables, and inventories. As the fraction of the labor force involved in agriculture and manufacturing decreases and the market economy becomes predominantly services and knowledge industries, its major activities become precisely those where the household excels. Furthermore, as taxation of market economy transactions (e.g., income tax) becomes more burdensome, this creates an incentive to spend time and capital outside the market economy. Thus at the same time that capital-intensive industries (e.g., energy supply industries) are tending to depend more and more on government subsidy and risk absorption, low-capital service activities may be shifting back to the household.

Decentralization of energy sources is both a component of the broader decentralization issue and also a conspicuous symbol for attracting attention to the decentralization cause. The issue is probably best seen as having at least three different aspects—technical, control, and symbolic.

Technically there are no compelling reasons to make decentralization of solar energy exploitation an important issue. Economies of scale in solar technology go both ways. Both the centralized solar-electric plant and decentralized heating and cooling have significant roles, and neither excludes the other. Decentralized solar electric power, particularly with advances in storage and photovoltaic techniques, has some advantage from the standpoint of system resiliency. From a technical standpoint, considering factors of economics, system performance, aesthetics, public safety, military vulnerability, and multiple use of sunlit area (e.g., collectors on rooftops and over highways), there will be applications where on-site solar technology fits and others where centralized solar electric technology comes out ahead. However, these criteria alone are not likely to decide the outcomes; selections will be strongly influenced by the issue of decentralized control.

Decentralization of control is an issue both at the individual level and at the system level. Individually, concerns are expressed that modern industrialized society engenders a sense of personal alienation and impotence, and hence a desire for ownership and/or control of the technology that affects one's life. Thus it becomes a matter of moment, for example, whether energy supply systems are individually owned or leased from a community-owned public utility, or, on the other hand, are obtained from or owned by a private power company. Control of energy sources (by individuals, communities, Indian tribes, etc.) is a way in which individuals and groups attempt to ensure a voice in decisions that affect their welfare.

At the system level, distribution of control tends to increase the adaptability and resilience of the system (see C.S. Holling, 1969). Resilience is a measure of the persistence of ecosystems and of their ability to absorb change and disturbance and still maintain the structural integrity of the system.

Thirdly, the symbolic power of the decentralization issue should not be underestimated. Solar energy is democratic; it falls on the rich and the poor, the weak and the powerful. Decentralized solar energy symbolizes keeping it that way—particularly on-site energy gathering at the individual home or community level. The issue of decentralized solar power is symbolic of a greater issue, the preservation of liberty and equity through maintaining some independence from the "big system." It is for some an ideological credo. As in the theoretical foundations of free-enterprise democracy the principle of control and ownership of property was considered essential to liberty, so the principle of control over indispensable energy supply is now put forth as a precondition of liberty.

Thus there is considerable reason to believe that the issue of decentralization of energy sources may turn out to be surprisingly vigorous and persistent, and that the political insistence on stronger federal support for decentralized solar energy will be far stronger than would be expected on the basis of economic and technical considerations.

5. Predominant Societal Goals

Perhaps most fundamental of all is the issue of what societal goals should predominate. There is abundant evidence that the traditional national goals of material progress and dissemination of "the American Way," which seemed so meritorious and unconfusing to our grandparents, do not command the same commitment from today's citizens. Emergent values and goals are challenging the adequacy of those traditional goals. These emergent values place more emphasis on individual development as spiritual being in community with fellow wo/man and nature, and less emphasis on material accomplishment per se; more emphasis on creative work as an end in itself, and less on work to gain economic goals; more emphasis on the fitness of the social environment for human growth and development, and less on technological and economic growth as ends in themselves. (See, e.g., Yankelovich, 1974; Lodge, 1975; Fromm, 1965; Roszak, 1972; Markley, 1974.)

Although it is impossible to be precise either about what goals guided the society in the past or what may guide it in the future, the tension between old and new is evident and present in every energy-related issue. The basic point is that energy is a *means*, not an end. Thus, the question of how much energy and from what sources must be embedded in the question: "To what end?"

Because goals are related to structure, changes in goals entail significant changes in social and political institutions. Institutions resist change; thus continuing conflict can be predicted with some certainty. Such issues as the amount of energy the society should plan for in the future and how determined the society should be in developing solar technology in preference to less benign technologies, gain their imperativeness in part because they are so intimately related to this fundamental tension between traditional and emerging goals.

6. Rationality Governing Decision Making

The sixth basic societal issue with which energy issues interlink centers around the role of economic rationality in societal decision making. It is obviously closely related to the goals issue. However, to identify it more clearly it is treated separately.

Basic sociopolitical decisions at whatever level—community or national—involve noneconomic factors, and often, explicitly or (usually) implicitly, basic philosophical issues. Civil rights, welfare, foreign aid, and environmental protection programs provide numerous obvious examples. It is well known that economic rationality has both its strengths and its weaknesses as applied to such decisions. On the one hand it has been argued that the most rational and politically satisfactory decision rationale involves incorporating as faithfully as possible all relevant factors into the economic framework. The counter argument contends, on the other hand, that applying economic rationality where it doesn't fit has led to unwise policy choices. This basic tension is a key to many contemporary issues surrounding energy and resources.

Economic rationality is characterized by concern for precision in putting relevant data in quantitative form, by emphasis on such criteria as efficiency and minimum cost per unit of output, by comparison of direct monetary costs and benefits in judging among alternatives. It focuses on the question of how society chooses to employ scarce productive resources that have alternative uses. It employs analytical techniques for transforming noneconomic costs (e.g., environmental degradation, increased social tensions, illness, and death) into monetary amounts to facilitate comparison. It handles the future rationally through letting future values have an appropriately discounted influence on present decisions. It is adaptable to handling uncertainty and risk through probabilistic methods (e.g., the likelihood of a nuclear accident or terrorist bomb, the chance that largescale fusion power will turn out to be infeasible in the next century).

Economic rationality is particularly favored for selecting and justifying decisions within government and business because of its credibility. It provides a set of rules for making choices that can be supported on empirical and logical grounds and are relatively defensible against a charge of biased value judgments. It allows demonstration to the taxpayer of what he or she is getting for the tax dollar. It impresses with its quantitative hardheadedness.

And yet, with recognition of these strengths of economic rationality, the criticism is nonetheless put forward that economic considerations have come to dominate over sociopolitical considerations in ways that often lead to questionable decisions. We have seen, for example, that in terms of cost solar technology competes poorly today with fossil fuels (except for space and water heating and a few other applications). Yet solar energy has important advantages that are difficult to include in the economic calculus. Solar energy is essentially nonpolluting. It is relatively safe and free from unanticipated consequences—it does not depend on new breakthroughs to overcome the problems caused by previous breakthroughs. Employing solar energy is living on "income" energy rather than "capital." It helps conserve limited fossil fuels for future generations. When families heat their homes with solar energy from their own rooftops it often seems to "mean" something different than when the home is heated with gas from the gas main.

It is common in economic discussions of energy issues to admit that our decision making is sometimes faulty in not taking adequate account of such "externalities" as the impact on the aesthetic enjoyment of nature lovers, the extermination of species, effects on the wholesomeness of the environment in which children are raised, the subtle erosion of traditional values, the welfare of underdeveloped nations, and the welfare of generations not yet born. Various correctives are proposed, among them government intervention. When there are external diseconomies that affect society as a whole, measures such as effluent taxes that reflect the public diseconomies into the equation of private decision making and a social discounting of the future at less than the usual rate can help ensure that the externalities will influence decision making. It is becoming evident, however, that the problem is more fundamental than these palliatives can cure.

In the theory of the market economy individuals and organizations make many diverse decisions that all, somehow, add up (with the aid of Adam Smith's "invisible hand") to satisfactory overall social choices. We recognize the efficiency of the market as a superb mechanism for ordering this immensely complex process. What usually goes unnoticed, however, is the important though subtle role of the culture in guiding the process. If, for example, the culture contains no ethic of protecting the poor and the weak (whether persons or nations), then market decision making will make the powerful richer and the weak poorer. If the culture has negligible concern for future generations, the future will be discounted at rates that profit the present generation, which is another way of saying future generations be damned.

These arguments indicate that the question of long-term energy policy becomes the question of what cultural overlay, what kind of rationality, is to guide the society's choices.

Paul Diesing (1962) delineates five distinguishable kinds of rationality that operate in modern society: technological, economic, social, legal and political. He describes how economic rationality has gradually been gaining dominance over social and political choices:

> Most of the sociocultural changes occurring in the Western world in recent centuries are either a part of, or a result of, economic and technological progress. One cultural element after another has been absorbed into the ever-widening economy, subjected to the test of economic rationality, rationalized, and turned into a commodity or factor of production. So pervasive has this process been that it now seems that anything can be thought of as a commodity and its value measured by a price...time, land, capital, labor; also personality itself, ...art objects, ideas, experiences, enjoyment itself, and even social relations. As these become commodities they are all subject to a process of moral neutralization. (p. 5).

Decisions that in their nature involve the emotional energy and symbolic power of social rationality and the plurality of values and norms that characterize political rationality are based instead on neat and quantified but limited economic rationality. Economic goals have substituted for social goals; what are properly means—technology and the economy—have been elevated to the rank of ends.

The issue really arises over where the boundary is—which decisions are properly the realm of economic rationality and which are appropriately dominated by social or political rationality. In presenting strongly the challenger's viewpoint we do not mean either to overlook the role that economic rationality has played in freeing society from traditionally sanctioned inequities and injustices, nor to enshrine one of Diesing's five types of rationality as somehow higher or better than the others. Economics has provided a rational accounting framework for debate; this in turn has contributed to the democratization of authority, and to the rise of self-determination on the part of the poor, the ethnically discriminated against, women, and the young. In other words, economic rationality has had powerful social consequences. Furthermore, choices made with social and political rationality are not intrinsically superior to those where economic rationality predominates. The presently constrained low prices for natural gas are a result of a social decision to limit costs to what society deemed appropriate levels. This decision is not proving to be an obviously wiser choice than letting market forces determine prices and handling inequities some other way.

This issue—how society makes different decisions—is not a theoretical nicety: It is an essential key to the puzzle of why our most sophisticated decision making techniques can lead to choices with socially negative outcomes. As Vickers (1970) observed:

> The dominance of technology has infected policy-making with...bogus simplifications...due in large part to the rampant misunderstanding of what economics is about—a misunderstanding which has entered so deeply into Western culture as to affect economists as well as laymen. Classical economics is concerned with markets and with the interaction of individual buyers and sellers in markets. The values of which it takes account are the market values to individuals of what they buy and sell. It takes no account of profits or losses which fall on third parties, still less of costs and benefits to the natural environment. ...The limited concepts of market economics are generalized far beyond the area of their validity...This mischief is multiplied by the dominance which economic valuations have gained...As an economist (Schumacher) has written—"Call a thing immoral or ugly, soul-destroying or a degradation of man, a peril to the peace of the world or to the well-being of future generations; so long as you have not shown it to be 'uneconomic' you have not really questioned its right to exist, grow, and prosper." Never did a concept so limited and so factual attain a meaning so general, so normative and so saturated with unjustified connotations of value.

Economist Kenneth Boulding (1969) has made a distinction between economic decisions, appropriately made with the aid of economic rationality, and "heroic" decisions—such as the decision to initiate an exploration of outer space, or to husband resources and use renewable energy sources— which must be made another way. One of the chief architects of our present political system, Edmund Burke, would have agreed, from his view of the social contracts with the yet unborn:

> Society is indeed a contract...[but] as the ends of such a partnership cannot be obtained in many generations, it becomes a partnership not only between those who are living, but between those who are living, those who are dead, and those who are to be born.

B. THREE REPRESENTATIVE VIEWS OF SOCIAL REALITY

Ultimately, all questions of how much energy and in what form are part and parcel of the goals question—*to what end?*

Hence, all major energy policy decisions involve a comprehensive pattern of surrounding issues, and this larger pattern is perceived in quite different ways by different parties at interest. This fact is evident in the public debates over energy issues—adversaries sometimes appear to be talking about different realities. The complication introduced by this fact is of extreme importance to democratic decision making, as we shall see in this section.

1. Methodological Comment

Everyone has seen the type of visual illusion in which the observer sees, alternatively, a particular pattern as "figure" against the remainder of the display as "ground," or else the reverse (Figure 5-1). One observer may see a particular pattern, while another may see a wholly different configuration. In one sense it is quite inappropriate to argue which pattern is the "true" perception, or to try to convince another that the pattern seen is the "wrong" one. Something like this clearly happens in human affairs. One observer will perceive in a situation a particular meaning and a second, with essentially the same data at his disposal, perceives the situation quite differently.

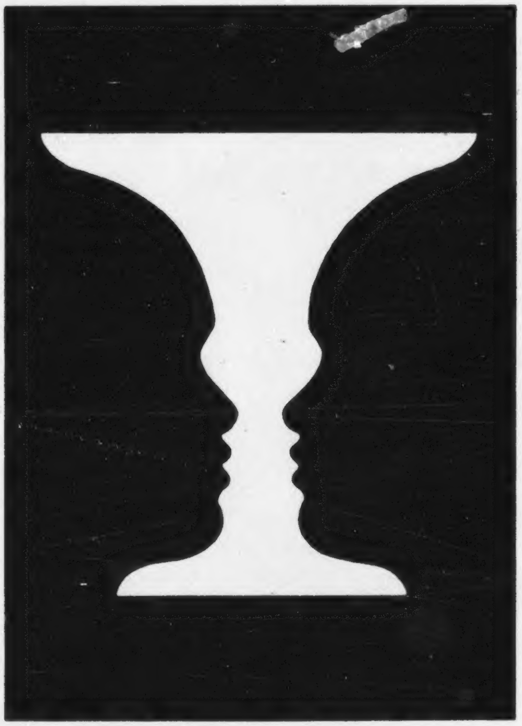

Figure 5-1 Example of Alternative Perceptions

The Japanese movie *Rashomon* was based on the tale "In a Grove" (Akutagawa, 1952) In this story a robber assaults a couple in a cedar grove, and the husband is stabbed to death. The incident is described by a woodcutter who found the body, the police commissioner who arrested the robber, the robber, the wife, and the murdered man (through a medium). Each of the five has a distinctly different impression of what happened. The power of the story, as the introduction of the story remarks, is that the five sets of conflicting statements "undermine our prosaic confidence in distinguishing between subjective and objective, truth and fiction." The American anthropologist Oscar Lewis (1959) used a "Rashomon technique" based on this concept in his studies of the culture of poverty.

Ruth Benedict (1934) introduced the concept of patterns of perception in *Patterns of Culture* as her basic analysis tool for understanding and comparing societies. She emphasizes the potential utility of the concept in illuminating goals, political conflict, and decision making in modern society. Graham Allison (1971) employed such a technique for analysis in his study of the Cuban missile crisis. Kuhn in 1970 used the word paradigm for a more expanded concept—the whole pattern of perceiving, thinking, values, and doing associated with a particular vision of reality.

We stress these points because, in general, people are not aware of the extent to which the reality they see is subjectively shaped, and that what they "see" tends to substantiate the picture they bring to it. Nor are they aware of how much that "picture" is shaped by culture, education, advertising, influential persons, the news media, and interpretations of past experience.

Many social scientists have noted this phenomenon. Anthropologists in particular are aware that persons growing up in different cultures literally see different realities. Gregory Bateson (Ruesch and Bateson, 1951) anthropologist, states flatly:

> Man lives by propositions whose validity is a function of his belief in them... These propositions, in fact, about the world in which we live are not true or false in a simple objective sense; they are more true if we believe and act upon them, and more false if we disbelieve them. (p. 217).

The sociological theorem of W. I. Thomas states: "If men define situations as real, they are real in their consequences." The observation that beliefs (conscious and unconscious) tend to influence perceptions, sometimes to a startling extent, is supported by copious research on expectancy set, experimenter beliefs, and placebo effect in studies of psychotropic drugs, hypnotic phenomena, hypnotic susceptibility, sensory deprivation, etc.

We want to suggest that this concept may be useful in interpreting the energy-policy implications of the impact assessments and scenarios derived in this study. If such an idea appears to be a weak tool in comparison with the seemingly more precise methods of statistical analysis, trend projection, and computer-based modeling, it is well to recall that just such a concept is central to modern historical methodology. History is intelligible, as has been said, in the sense that historians make it so. The incomplete data and fragmentary descriptions of events of the past are viewed through, and in turn contribute to, some pattern of interpretation, some overall picture of meaning, some historical perception. The richer understanding gained through the effort to perceive through more than one competing perception becomes evident by comparing United States and British histories of the American revolution, or North and South versions of the Civil War, or Black and White histories of the early United States. Thus, our attempt to use it to "make sense" out of the extremely complex contemporary energy situation is not without reassuring precedent.

The analysis of policy issues from the assumption that groups experience different perceptual realities is, in a way, similar to the more familiar stakeholder group analysis discussed in the last section of Chapter 3. There is, however, a significant difference. The function of stakeholder group analysis in a technology assessment is to illuminate the political process by assessing a critical political issue and clarifying who wins and who loses and by how much. The analysis in this chapter, on the other hand, is more concerned with how the different groups would define winning, and what factors they consider of fundamental importance—to the eventual end of improving communications and facilitating the common seeking of solutions.

There are, of course, as many perceptions of the energy debate as there are observers, and it is impossible to analyze all of them. There do appear to be patterns, however, to the arguments on energy issues, and it is our purpose in this section to illuminate those patterns. Just as the three scenarios of Chapter 2 were selected from a much larger array of possible energy projections, so we have selected three different perceptions or worldviews from the array of all possibilities.

It may be quite impossible, at this time, to establish which picture among these pictures of reality is "correct," because the available data can be fitted into more than one pattern. Each of these three views has significant representation among decision makers, analysts, and the body politic. Yet each of the perceptions tends to lead to quite different actions, and when persons appear to be arguing about technical issues or choices among energy options, they may in fact be arguing from different fundamental perceptions of the nature of social reality. Real-life political decision making has to be carried out not only amid data-uncertainty, but amid pattern-uncertainty, and our intention here is to explore how that can be done most rationally.

2. A Prevalent View (Perception A)

The first of these—identified simply by the term "Perception A"—is summarized in the accompanying box. It tends to assume that the general pattern of emphases and policies that worked well for the U.S. economy in the past is also our best bet for the future. It tends to consider environmental concerns and the OPEC price hike and embargo as perturbations on an upward—sweeping path of continuous development. Like other perturbations, such as World War II and the rising expectations of underdeveloped nations, they are to be met and transcended.

Viewed from the perspective of Perception A the energy problem is essentially one of developing new supplies to meet the expanding energy needs of a dynamic society. Along with this, conservation measures would need to be adopted to reduce wasted energy. Although it is recognized that the United States is running short of domestic natural gas and petroleum and can ill afford to become too dependent on foreign sources, it is also true that there are ample alternative energy sources that merely await development (e.g., coal, shale, solar, the fission breeder reactor, and eventually nuclear fusion).

The proven accomplishments of technological solutions to past problems ensure that the public will support such a technological approach to the problem of maintaining adequate energy supply. This may entail subsidizing developmental costs and industry's risk protection where necessary to assure the timely development of new energy sources and the nation's energy security. Environmental costs of large energy projects should be minimized—e.g., by reclamation of stripmined land. Nevertheless, some environmental costs are inevitable and will have to be accepted in preference to the economic and social penalties of running out of energy. Similarly, some regional sacrifice (e.g., in Alaska and the western energy-producing states) will have to be accepted to further the overall national interest. The goals of ongoing economic, material, and technological growth provide an adequate cultural bond to ensure concerted effort to solve the nation's energy problems, including resolving safety, ecological, land-use, and water rights conflicts.

CHARACTERISTICS OF PERCEPTION A

World Responsibility. The benefits of a high-growth, high-technology, free-enterprise society as compared with any feasible alternative are obvious and generally agreed to. Such a society provides the best hope for raising the nation's poor, and the poor of the world, to a higher state of material and social well-being. Hence a U.S. responsibility with regard to the world is to maintain its technological and economic leadership, and to aid poorer nations to industrialize and modernize.

Economic Growth. Economic, material, and technological growth must continue at least for the present. There will eventually be a gradual leveling off of some aspects of economic growth and resource usage. But those neo-Malthusians who see crippling shortages in the near future are ignoring our demonstrated ability to cope with such problems by technological innovation, substitution, exploiting lower grade ores, etc. When these factors are taken into account, we are nowhere near ultimate resource limits. The social costs of abruptly lowering economic growth rates, particularly in terms of unemployment and dooming the poor to hopelessness, are too high to consider.

Regulation. Regulation will be increasingly necessary. That is part of the price we pay for the benefits of highly complex modern society. But regulation should be applied with moderation; we must not kill the goose that lays the golden eggs. A central concern of the federal government should be to do the necessary regulating in such a way that business has the stable climate it needs to maintain a healthy economy and risk new technological ventures.

Decentralization. On the whole, centralization promotes efficiency and effective management. We need to alleviate any problems that excessive centralization appears to cause, and in particular we need to limit centralization that tends to eliminate competition. But it is important to be realistic. Some of the decentralization talk is romantic nonsense; we can never go back to the family farm.

Goals. The ability to achieve humane goals has been, and will continue to be, made possible through economic growth and material and technological progress.

Decision Making. Decision making in society needs to be made on as rational a basis as possible. There can be little doubt that quantification of data and the development of the conceptual frameworks of economics have contributed greatly to this desired objective.

It is probably fair to say that U.S. resource and energy policy has thus far been shaped mainly by a Perception A point of view. This view is implicit in the reference case and solar emphasis scenarios of Chapter 3. Perception A assumptions are consistent with the sorts of federal interventions assumed there: subsidies, price guarantees, and other investment incentives for development of new energy supplies; relaxation of environmental protection regulations where these are in conflict with vitally needed energy supply; strong federal emphasis on safe nuclear waste storage; federally sponsored water transfer programs for vitally needed energy projects; revision of water rights and mineral rights legislation where needed to spur energy developments; provision of incentives for energy conservation where this will not have negative economic impacts; support of solar and geothermal energy research with investment incentives for pilot plants and large solar-electric and geothermal-electric developments.

Whether or not public attitudes will continue to support a Perception A view of the world can be tested by monitoring the public press, by survey data, by analysis of Congressional hearings and press responses to Administration policy documents, by examining the stands of and observing the amount of public support given to actions of environmentalist and public-interest groups. If they do remain supportive, a drastically lowered projected energy demand (for example, a future national demand near or lower than the 1973 peak of around 75 quads) would be both unacceptable and implausible because of the perceived implications this would have for lowered economic productivity and increased unemployment. Instead, it would be reasonable to expect a modest continuing rise in GNP and corresponding growth in energy demand, and a large amount of future energy supply coming from massive coal and shale developments, breeder reactors, and other advanced energy supply technologies–in other words, something like the reference case scenario of Chapter 3. It would also be reasonable to expect that considerable promise would be found in large centralized solar power installations, including such exotic technologies as ocean thermal gradient exploitation and satellite-based collection if their costs can be lowered enough.

3. A Contrasting View (Perception B)

A contrasting view, which we shall call Perception B(summarized in the accompanying box), is toward the other end of the spectrum. It tends to see "business as ususal" as bankrupt strategy. It sees a major reordering of values and priorities in society as essential. The future is a "whole new ball game." Various indicators help to delineate the central theme of this pattern of perception and its associated attitudes. Daniel Bell (1973) in describing "post-industrial" society noted a shift from an "economizing mode" to a "sociologizing mode":

> The "economizing mode" is oriented to functional efficiency and the management of things (and men treated as things). The "sociologizing mode" establishes broader social criteria, but it necessarily involves the loss of efficiency, the reduction of production, and other costs that follow the introduction of noneconomic values (p. 43).

Three years later he saw "the cultural contradictions of capitalism" growing more acute:

> Life in pre-industrial societies—still the condition of most of the world today—is primarily a *game against nature*...Industrial societies... play a *game against fabricated nature*...A post-industrial society is thus...a *communal* society...Yet these changes in social organization may, in an intangible way, herald more—a change in consciousness and cosmology. (Bell, 1976, pp. 148-149).

But the emergent perception we are characterizing as Perception B goes far beyond Bell's post-industrial society, which is, after all, essentially an extension of past trends rather than a consequence of trend shifts and reversals. Daniel Yankelovich (1972) gives survey evidence of what he terms a "New Naturalism" including emphasis on harmony and relationship with nature, on the search for sacredness, on the nonrational—the intuitive, aesthetic, and mystical—and on community. The strength and actions of the environmentalist movement, the "human potential" movement, the "appropriate technology" movement, and similar public interest groups provide another sort of indication.

The flavor of Perception B can be comprehended from such publications as *The CoEvolution Quarterly* and *The Mother Earth News,* and the papers from numerous "appropriate technology" groups. Representative expositions of this perceptual pattern include E. F. Schumacher's *Small is Beautiful, The Energy Primer* (Portola Institute), *Moving Toward a New Society (Bowan et al., 1976), Communitas* (Goodman and Goodman, 1960), and Richard Gregg's early paper on "Voluntary Simplicity" (1974). The distinguishing attitudes from these writings include a strong ecological ethic; identification with nature, fellow man, and future generations; and sympathy with rising demands for self-determination on the part of communities, ethnic groups, and poorer nations. There is a deliberate search for meaning and commitment, seen as lacking in modern industrialized society. These attitudes are reflected in a lifestyle characterized by voluntary frugality ("doing more with less"); appreciation of the simple life and simple virtues, of relationships with other persons and with nature, and of work that fosters these (e.g., handcrafts, organic gardening). The technology favored is "appropriate" technology that is environmentally benign, energetically frugal, resource-conserving, and understandable and usable at the individual or community level.

Perception B involves a set of assumptions about our energy future something like the following:

- The supply of fossil fuels is limited by attitudes regarding the social and environmental consequences of their extraction and utilization (and ultimately, of course, by the finite supply that can be extracted with a net energy advantage). Nuclear power, both of the conventional and breeder types, involves problems of public acceptance that are far from resolution and perhaps impossible to resolve. Fusion is only a faint light on the horizon. Dependence on foreign oil import for a significant fraction of the nation's energy supply involves serious economic and political problems. Burning up domestic resources faster to achieve energy independence at present consumption rates steals from future generations. ("Strength through exhaustion," the policy has been called, or "Burn America First!")
- Thus, it is imprudent not to shift as far and as rapidly as possible in the direction of (1) husbanding energy resources through energy conservation, use of low-energy materials and processes, and altering consumption habits; and (2) developing renewable energy sources, mainly solar and geothermal. This course is sound, even if some satisfactory way is ulti-

mately found to provide much of our power from fusion processes. Following it, we will avoid committing future generations to an unsustainable course and the lesser developed societies to permanent energy poverty.

- Hence, the roles of coal and imported oil are essentially to sustain the economy through a period of transition from fossil fuels to renewable energy sources. A role of conservation is to minimize the difficulty of this transaction.

- Large energy projects are likely to be subject to delays, increasing costs, and cancellations, due to protests over safety, environmental and social impacts, to increasing problems with legal liabilities, and to difficulties in obtaining investment capital. This is an additional reason conservation should be a dominant theme in the nation's energy policy.

- The determination of some developing countries to bring about a redistribution in use of the earth's resources provides yet another reason for reduction of energy demand by the industrialized nations, and for development of energy-frugal and materials-frugal technologies.

In this view even the low demand scenario of Chapter 3 doesn't go far enough in the direction of:

- Developing institutional and cultural incentives for comprehensive energy conservation and curtailing of unnecessary energy use;

- Reducing use of high-quality energy (e.g., electricity) for end uses that do not demand it (e.g., the nearly half of electric end-use energy going directly to low-temperature heat)

- Increasing use of "soft" or "appropriate" technology—relatively decentralized, using renewable energy sources, flexible and relatively ownable and controllable by the operator

- Sophisticated use of fossil fuels as a transitional technology to renewable energy sources.

(Amory Lovins [1976] explored the possibility of such a low-demand, renewable-energy scenario and concluded that within half a century there could be less annual energy demand than at present, with no sacrifice in quality of life and with practically all of the energy coming from renewable sources.)

Reduction of energy dependence coupled with decentralization of energy sources is a crucial issue in Perception B. We discussed this topic earlier; Ivan Illich makes the point even more strongly in *Energy and Equity* (1974):

CHARACTERISTICS OF PERCEPTION B

World Responsibility. A "fairness revolution" is necessary; the rich nations consume far more than their share of the Earth's limited resources and contribute far more than their share of environmental damage. The insistence of the poorer nations on a "new international economic order" is justified; a new order is essential to any hope of eventual world political stability. Richer nations like the U.S. need to consume less, support the redistribution of resources, and recognize the validity of societal choices other than Western style industrialization and agribusiness.

Economic Growth. The social and environmental costs of continued material and technological growth in the pattern of the past, and of continually rising per capital energy consumption, are intolerably high. There must be a leveling off. There is a "new scarcity"—of physical resources, waste-absorbing capacity of the environment, resilence of planetary life-support systems—qualitatively different from the scarcity problems "solved" by modern industrial production. The response to this must be a voluntary choice of simplicity and frugality in the life style of the society, and a renunciation of the consumption ethic and the growth addiction.

Regulation. The only way to avoid regulation that will ineluctably infringe on civil rights and liberties is through reduced demands on resources, and simplification and decentralization of society.

Decentralization. Decentralization of control, of technology, of population, is necessary if we are to have a humane, just, and free society in the future. In particular, this implies "appropriate technology" and the strengthening of community.

Goals. Humane ends can be attained only by putting more emphasis on fostering human growth and development and reducing the emphasis on material accomplishment, on consumption, on economic growth as an end in itself. The goal is to *be*, rather than to *have* or to *control*.

Decision making. Decision making in society needs to be made as participative as possible, and to be guided more by humane criteria. The new mood is a reaction against the predominance of materialistic values; against tendencies to put human affairs and even lofty goals in economic terms, to assume that the wisest decisions are made on an economic basis, and to elevate means—production and consumption of goods and services—to the position of ends. It is necessary to judge a social choice, not in the narrow sense of profit and efficiency, of growth and productivity, but in the broader sense of social efficiency—does it pollute the environment, squander resources, bring about disemployment, stultify workers, misguide consumers?

> High energy consumption...means decreased distribution of control over that energy...Participatory democracy postulates low energy technology. (p. 5).

Perception B characterizes a significant and apparently increasing fraction of the electorate. If this group grows in influence, the impact on energy policy will be substantial. Societal development of breeder reactors, massive shale and synthetic fuel development, and even some of the more exotic large-scale solar technologies would become quite questionable. It seems likely that large-scale fossil and nuclear projects would continue to be delayed and canceled because of environmental and safety objections, perhaps to the point that they become economically and politically infeasible. On the more positive side, strong support could be expected for initiatives designed to move toward a more energy-frugal, renewable-source based society.

4. A Third View (Perception C)

There are a wide range of other perceptions that depart widely from either Perception A or B, including the perception that we have all been duped by the large energy companies and there is no serious energy problem at all. One is singled out for examination, which we will term Perception C (summarized in the accompanying box). In this case its importance is not because it characterizes a large pressure group in society, but rather because the policy implications are so great if it should turn out to be an accurate perception.

This third view shares most of the value positions with Perception B. However, it differs from Perception B in that it sees no way these values can come to dominate societal institutions without a most funda-

CHARACTERISTICS OF PERCEPTION C

World Responsibility. A "fairness revolution" in the world is necessary; however, this cannot come about without fundamental change in the nature of modern society. The basic paradigm of industrial society contains the seeds of international confrontation over finite planetary resources. It contains no rationale or incentive for planetary stewardship or for more equitable distribution of the Earth's resources. The industrialization trend and the goal of material progress, in the absence of more transcendental values, lead ineluctably to problems of resource depletion, environmental deterioration, hazardous substances, threats to the planet's life-support system, and international competition for the means to survive. Thus the desirable goals of Perception B cannot be achieved without a fundamental transformation of industrial society and its institutions.

Economic Growth. Fulfilling work is necessary to the well-being of persons. The trends of increasing industrialization and automation, however, lead to less and less intrinsic reward in work. Environmental and resource depletion impacts put constraints on expanding production and hence on employment. Thus, there develops chronic unemployment and underemployment. These worsening tradeoffs are not accidental, but intrinsic to advanced stages of a society that evolves around the present industrial paradigm.

Regulation. The regulation dilemma, too, is perceived as a consequence of the playing out of the industrial paradigm. Consequently, the attempt to continue past growth patterns and then control the negative consequences is a losing game. In general, the higher the level of energy use (or economic production) the greater the need for regulation—and hence the greater the threat to civil rights and liberties.

Decentralization. Decentralization is seen as one of the essential characteristics of the post-transformation paradigm. Decentralization of technology, population, production, control and mass culture can foster the values of self-determination, community, ecological stewardship, equity, and liberty.

Goals. Like Perception B, this view sees a resurgence of emphasis on humane goals. Industrialized society is increasingly unable to provide goals that will enlist the deepest loyalties and commitments of its citizens. Inherent in the post-transformation paradigm is a reassertion that man has two complementary aspects, the physical and the spiritual, neither explainable in terms of the other nor to be denied because of evidence for the other. Within the spiritual aspect, which the rising prestige of positivistic science for a time tended to debunk and confute, are to be found the proper goals for the individual and society. Thus, the transformation that is perceived to be in process goes (as in Kuhn's use [1970] of the term paradigm) to the level of the basic vision of reality around which societie's institutions are constructed.

Decision Making. The domination of decision making by economic rationality is an intrinsic aspect of the industrial paradigm. This characteristic, and the problems it engenders, will change only when the paradigm changes.

mental transformation of culture and institutions—involving a transition that will be sudden (in an historical sense, with dramatic change in no more than a few decades), traumatic, and risky. It will come about not because some group promotes revolutionary activity, but because the attitudinal support necessary for the functioning of social institutions becomes too weak to sustain the present order.

In Perception C the basic trends of industrialized society are seen as leading toward a fundamental crisis, of which the energy problem is but one manifestation. Each of the six basic issue areas identified in the preceding section contains within it an aspect of the perceived crisis (see box).

Perception C implicitly assumes that the trends that have characterized industrial society thus far cannot continue much longer. But any major departure from those trends would undoubtedly be accompanied by some severe wrenching around of the economy and social institutions, and some very significant cultural change—a much more fundamental change than that accompanying technological innovation that, in the recent past, has brought large-scale rural-urban migrations, marked lifestyle changes, whole new modes of transportation and communication, vast alterations in the types and distribution of goods and services, and a host of new roles for government. Essential modification of the industrial thrust would entail, in contrast with the acceleration accompanying technological advance, a major change in direction and a fundamental reordering of the goals of society.

Thus, the question we ask resolves itself into two: How plausible is *planned* rapid social change, and how plausible is unplanned but *managed* rapid social change? How plausible, for instance, is a scenario (such as is desirable in Perception B) in which the government leads the nation toward a low-energy "husbanding" society without waiting for circumstances to force a reduced-energy mode? And how plausible is a shift to some sort of "trans-industrial" society in response to a spreading of Perception C?

Even though this sort of basic paradigm change may seem most unlikely, we must note that there have been infrequent examples of "extraordinary" change in various revolutionary epochs (e.g., the Copernican revolution, the Industrial Revolution in England, the shift from colonial to national status of various African and Asiatic countries after World War II). Such revolutionary societal change has been studied to some extent by anthropologists (e.g., Wallace, 1970); sociologists (e.g., Johnson, 1964; Davies, 1971; Teryakian, 1967; and historians (including, on the grand scale, Arnold Toynbee in *An Outline of History,* 1946). Broadly speaking, two conditions appear to be present in these cases: (1) widespread "extraordinary" individual change in perception of the flagging meaningfulness of the old order and the promise of meaning and commitment in a new order, and (2) a withdrawal of perceived legitimacy or sense of appropriateness from the institutions of the old order. Perception C tends to see signs of these conditions in society today.

5. Contrasts Between the Perceptions

From the writings of various anthropologists (e.g., Benedict, 1934; Kroeber, 1963; Kroeber, 1944; Kluckhohn, 1949); and historians (e.g., Toynbee, 1946), we can deduce a simple model of society in which various elements of the society appear in concentric shells, as it were. Near the periphery are those aspects of society which are relatively changeable, directly observable, and quantifiable—e.g., events, policy decisions, economic indicators, technologies. At an intermediate level are cultural patterns, lifestyles, values, institutions, ethics, and mores—not so easily altered as those aspects nearer the periphery, but still changing over longer periods of time. At the core of the society is a relatively

		Impression of		
		Perception A	Perception B	Perception C
By persons whose own view is that of	Perception A	Right on!	Idealistic, impractical	Dangerous, revolutionary
	Perception B	Irresponsible	Right on!	In the right direction but too radical — more gradual, rational approach is better
	Perception C	Dangerous, dinosaur-like	In the right direction, but unrealistic about the extent of fundamental institutional change required	Right on!

Figure 5-2 Comparison of Three Alternative Perceptions

unchanging, largely unconscious but inferrable, basic paradigm including some sort of tacitly apprehended image of man-in-the-universe. This basic paradigm tends to endure through time and changes significantly only in the event of a thoroughgoing social revolution affecting all the more peripheral levels. In terms of this conception, Perception A perceives the energy issues as involving changes in the peripheral shell; Perception B views changes in the intermediate shell as well; Perception C sees the very core of society, the basic paradigm undergoing modification. (Another comparison appears in Fig. 5-2.)

		PERCEPTION		
		Perception A	**Perception B**	**Perception C**
SCENARIO	**Reference Case**	Of the three, this is the best future for the U.S. and the best hope of raising the standard of living of the poor nations. Above all, the nation needs enough energy to keep the economy rolling	The costs of this scenario greatly exceed the benefits. Strong measures must be taken to reduce energy demands below the levels of this scenario.	This scenario represents gluttonous use of energy in a world becoming resource poor. The outrageousness of social and environmental costs help demonstrate the need for a new social and economic order.
	Solar Emphasis Case	Solar energy should be stimulated only moderately; it is generally desirable to keep interference with the market to a minimum. It is also important to keep energy prices down to insure a strong economy.	The society must move in the direction of shifting to renewable energy sources and lowered demand. The strong stimulation of solar energy development in this scenario is highly desirable.	Stimulation of solar development is desirable; but the total energy demand is much too high. In addition, fundamental change in economic and social institutions will be required for a rational energy future.
	Low Demand Case	The low-demand scenario is absurd; it endangers all we have built up and imposes unnecessary sacrifices on the individual. It would inevitably bring a depressed economy.	We must choose voluntarily a scenario with energy demands as low as this or lower, in order to avoid terribly serious costs in the long run.	Energy demand as low or lower than this must be achieved, but this is incompatible with the present structure of the economy. Fundamental change, probably coming about through a traumatic transition period, will be necessary to reduce environmental and social assault to tolerable levels.

Figure 5-3 Attitudes of the Different Perceptions Toward the Three Energy Scenarios

Perception C, despite its emphasis on a wrenching transition period, appears basically as optimistic in its outlook as Perceptions A or B. It is not a doomsayer's outlook. James Robertson (1976), for example, emphasizes that both signs of "breakdown" and of "breakthrough" to a new stage of civilization are present. Stavrianos (1976) writes glowingly of "The Promise of the Coming Dark Age."

Basically, the difference between Perceptions B and C is the difference between continuous and discontinuous change (Figures 5-2 and 5-3). It is probably necessary to go back as far as the Scientific Revolution to find an adequate example in Western history to clarify the distinction between Perceptions B and C. Perception B is analogous to the perception that the new discoveries of Copernicus, Galileo, Kepler, et al, could all be gradually accommodated into an evolving worldview without discontinuous change, even though the total change might eventually become quite extensive. Perception C, on the other hand, compares with the realization that something far more fundamental was involved—that the shift from medieval to modern images of man-in-the-universe was so profound as to affect every institution in society.

"Radicalization" toward this latter view may place more emphasis on one or the other of two issues: (1) the oppressive nature of the institutions of industrialized society or (2) the tendency of industrialized society to suppress understanding of the transcendental nature of man. The first issue is apparent in the writings of Ivan Illinch: the second characterizes the "Age of Aquarius" type of literature.

Like Perception B, C also sees the key solution to energy problems as abandoning the attempt to satisfy some sort of inviolate energy demand of industrialized society, and helping to bring about a fundamental restructuring of human affairs—including a lowered energy demand that is more appropriate to man's actual situation on planet earth. However, in Perception C a much more fundamental transformation is involved than changed lifestyles and implementation of a conservation ethic.

Since one of the main driving forces behind high energy requirements is the threat of high unemployment, the role of energy in the society cannot be separated from the role of work, particularly the sociocultural function of meaningful work. Thus, C perceives that restructuring for reduced energy demand implies fundamentally reevaluating the role of creative work in a meaningful existence. It implies challenging the industrial-age dogma that mechanizing work, or increasing physical efficiency and labor productivity, is always a gain in human terms. Energy use has to be considered in terms of its effect on the quality of work opportunities. This is not the same thing as simply making production more labor-intensive.

However, the entire pattern of the six issue areas identified in Section B is involved in this fundamental crisis of industrialized society. Such basic issues are unlikely to be resolved (or perhaps even clearly perceived) as long as the system appears to be doing passably well. Thus, attempts to delay or interfere with large energy projects (attempts which in Perception A might appear irrational or even unethical) tend to be seen in Perception C as justified therapeutic interventions ("radicalizing" actions to raise awareness).

As we have seen, all three of these perceptions represent views found among decision makers, analysts, and citizens. All have to be honored in some sense since each "fits" the observations of his environment as made by the person holding that view. Presently there appears to be no clear way of standing apart and objectively determining that one of the views is more "true" than the other two. No one of these three views can be disproven by "facts" drawn from another. Whichever view society comes to accept, that view will tend to become more "real." Does this mean, then, that choice among them is completely arbitrary, that one is as serviceable as another?

Even if there is no way at present of determining that one view is the "correct" one, each would, if predominant, lead the society to a different future. So it is extremely important, in the long run, which one society chooses.

There are criteria that can be applied to this choice—criteria which are relatively independent of perception, or rather, would seem reasonable in any perception. Perhaps the three most important of these relate to the following questions:

DOES THE VIEW IN THE LONG TERM LEAD TOWARD SYSTEM ADAPTABILITY AND, HENCE, TOWARD SURVIVABILITY?

There are certain laws of nature and universal properties of systems—boundary conditions and limits, if you will—that must be given in any perception. To the extent that they are ignored it would threaten the system adaptability and hence its surviveability. The laws of thermodynamics, the basic principles of cybernetic systems theory, the fundamental principles of ecosystem behavior and adaptability, do obtain—regardless of one's opinions. Some conditions for adaptation, for preservation of options, are ineluctable—they operate regardless of whether or not they are included in a society's picture of reality. (See, for instance, Georgescu-Roegen, 1975)

Adaptation refers to the processes by which living systems maintain system stability (homoestasis) in the face of short-term environmental fluctuations and, by transforming their own structures, through long-term nonreversing changes in their environment as well. Rappaport (1976) has discussed the conditions under which societies maintain adaptability. He concludes that "as energy flux has increased, the disparity between the direction of cultural change and the goal of biological survival has widened," raising the question of whether the continuing growth of high-energy industrialized society is, in the long term, maladaptive. Thus, an argument that, like the skater on thin ice, we can't risk stopping suggests, in and of itself, that the system has become less adaptive.

HOW DOES EACH PERCEPTION VIEW THE LONG-TERM TREND OF HUMAN CIVILIZATION?

Perception A is optimistic that our science and technology shall raise all of humankind to an era of prosperity undreamed of a hundred years ago (Kahn, 1976). Furthermore, economic prosperity is the sine quo non for enabling large portions of the population to share in the luxury of more non-materialistic values. Neither ecosystem stability nor social ethics have much importance to someone who is starving or enslaved. Yet proponents of B and C tend to see the exactions of modern, high-energy, industrialized society as destructive of such traditional values as a reverence for nature, humankind's spiritual development, and the democratic liberation from oppression by institutions. To the extent that their observation is justified and to the extent that Perception A remains the dominant culture, then there would be an increasing alienation of the individual from the institutions of society and a decreasing viability of the social order. An apparent new task for the social sciences will be to assess, not just within the national boundaries but in the global context, the function and dysfunction of society as the energy variable changes.

IS THE VIEW COMPATABLE WITH WHATEVER CAN BE DISCOVERED TO BE HUMANKIND'S MOST FUNDAMENTAL NATURE?

A contemporary description of our basic nature might suggest that *homo economicus* is to self-actualizing humankind as classical mechanics is to relativistic physics. In fact, psychology is now pushing the frontiers of research into the transcendental realm of human experience. It may not be immediately obvious that questions of energy policy relate directly to implications regarding the nature of man. And yet we know that societies as different as the reference and low demand futures we have studied include implicit assumptions that go to the core of our value systems—perhaps even to the core of our nature.

Whatever one's individual perceptions may be—whatever one's view of the world, be it A, B, C, or X—it is apparent that our answers to the three questions must, in turn, be transcended by the questions themselves. It is specious to think that any answer we formulate is "the answer" for it suggests that we shall not grow or change. That the questions remain as periodic tests for our perceptions is important—not that there be "truths" to which we agree.

6. Summary

In the public dialogue about the desirability of energy and economic growth, which is likely to get more acrimonious before it is finally resolved, there is a distinction to be made between the varying perceived '*interests* of stakeholder groups and the differing *perceptions of reality* which may exist. Of course, the two often overlap, as when a group's perceived interests are part of its picture of reality; on the other hand, groups with essentially the same perception of the basic social and economic reality may have quite divergent interests. The essential point is that society has recognized and legitimated ways of dealing with interest-group conflicts (e.g., compromise, arbitration, the adversary process in the courts), it does *not* have, in general, satisfactory ways of dealing with alternative perceptions of reality. One of the most constructive steps to be taken to reduce conflict and to help arrive at a long-term growth policy for the nation may be to *legitimate alternative perceptions of reality*, as a way of shifting the political process from an adversary mode to an exploratory mode. The adversary mode is a time-honored way of settling a dispute; it is not a satisfactory way of arriving at truth, nor at a wise policy.

In the present study we introduced the three Perceptions A, B, and C, to help understand some of the conflict surrounding energy-related issues, and hopefully as a tool to help improve communication and reduce conflict. If the various perceptions of the issues surrounding crucial energy decisions can be (a) legitimated, and then (b) explored together in public dialogue, it may be possible to move toward (c) establishing consensus on which perception, with the actions that follow from it, is most accordant with a long-term desirable energy future.

The energy choices presently being made by this nation are among the most important of any decisions in its history. Yet because of the tremendous degree of uncertainty about a rapidly changing society, the most sophisticated models and systematic theories can be as wrong as the simplest intuition. Some of our voices that are the loudest and most confident in our analyses and most profuse in our quantified results may also be the most in error. Assumptions about future attitudes and behaviors of people, which basically underlie all the models and projections, are precisely where the greatest undertainty lies. For these reasons we conclude that it is essential to deal with the issues raised here.

In the process of examining the diverse perceptions of the U.S. energy future over the next 50 years, the most critical of current energy-related questions has emerged: ***What are the full social benefits, costs, and risks of a national shift toward reduced growth rates of energy consumption and a growing reliance on renewable energy sources?***

That question cannot be separated from a fundamental reassessment of major priorities in our society and of our basic beliefs about man's place on the planet and in the universe—beliefs upon which our priorities depend. The issue of accelerating a shift to solar energy and other renewable energy supplies is not a matter of technological and economic factors alone; it involves the fate and future of industrialized civilization. The question of how much energy we as a society should consume is not simply a matter of how much is needed to continue our past ways; it points to a fundamental reevaluation of where the society is going, and wants to go.

The immediate challenge before this nation, indeed before the world, is to identify, explore, and assess alternative paths to the future and to choose from among them. As suggested here, while the debate may appear to be an economic one, basically it is much broader. It has everything to do with challenges to the conventional perception of reality. Most of the fundamental noneconomic, age-old questions about the nature of man and of the good society will be involved in this crucial process—and that is the critical reason it requires in all phases the enlightened participation of the public.

C. THE LONGER-TERM FUTURE

If any one unresolved issue emerges out of this analysis as being of commanding importance to the nation, it is the choice of a long-term energy future—the kind of society that we will be moving toward as the half-century time frame of this study comes to an end. In terms of the time spans of history, our energy choices are narrowing rapidly.

Within a century or so, fossil fuels will be a declining or nearly expended resource. Everything we examined in the course of this study suggests a great uncertainty about what we do after the fossil fuels run out. Unless some totally new technology appears of which at present we have no idea, there are essentially two choices. One is an energy future dominated by the nuclear breeder and/or nuclear fusion, with solar energy playing a secondary though important role. The other is a future in which society has rejected dependence on nuclear energy and has opted instead for primary dependence on solar energy with a stabilized level of energy use far less than presently projected levels. There are no other options.

It is vitally important that the nation's energy policy not turn out to have been like the judgment of the man who, having fallen from a tenth-floor window was heard to say as he plunged past the second floor, "I'm in good shape so far." It is possible to insure against that eventuality by encouraging the growing use of solar energy and supporting measures to use energy more judiciously. It would appear that the nation has the resilience to navigate gracefully this new course.

GLOSSARY

Annualized life cycle costs: The level payment necessary to cover principal, interest, taxes, insurance, fuel costs, operations, and maintenance for the life of the system.

Appliance saturation: A situation in which there is no opportunity for further growth in the appliance market.

Base load: The maximum continuous electrical demand. Typically constitutes about 75% of total energy output of the electrical system.

Bbl: Barrel.

Biomass: Terrestrial or marine plants and agricultural, forest, or municipal wastes than can be utilized for their energy content.

British thermal unit: Amount of energy needed to heat one pound of water one degree F.

Capital cost: Cost of construction (eg., of an energy process facility). This generally includes equipment, land, buildings, inventory, and working capital as required, but excludes interest during construction.

Constant dollars: Dollars as valued after accounting for inflation. Usually indexed to one year, as in 'constant 1975 dollars.'

EPA: U.S. Environmental Protection Agency.

Energy: The ability to do work.

ERDA: U.S. Energy Research and Development Administration.

Exajoule: 10^{18} joules; appromimately 0.95 quad

FEA: Federal Energy Administration.

Ffe: Fossil fuel equivalent.

Fossil Fuel: Coal, oil, shale oil, tar sands, peat, and natural gas.

Fuel cell: A device that electrolytically reacts oxygen and hydrogen to directly produce electricity and water. It is a reversal of the electrolysis of water.

HTGR: High-temperature gas-cooled reactor.

IIASA: International Institute of Applied Systems Analysis, Schloss Laxenburg, Austria.

Insolation: Solar radiation received at the earth's surface.

Intermediate load: The electrical load above the 24-hour base load that occurs from about 7 am to 9 pm (not including the small additional peak load that generally occurs between 3 pm and 9 pm). Typical constitutes about 20% of electrical output.

Joule: The work done when a force of one newton is applied over a distance of one meter. One Btu is 1055 joules.

Kilowatt-electric (kW(e)): A basic unit for measuring electrical power. One kW(e) is equal to 1000 joules per second (1000 watts).

Kilowatt-hour (kWh): A basic unit for measuring electrical energy, equal to 3413 Btu.

Light-water reactor: Nuclear reactor using normal water as a coolant and moderator.

LPG: Liquefied petroeum gas

Minemouth coal cost: The cost of mined coal. Excludes cost of transport to user.

Ocean thermal energy conversion (OTEC): An energy conversion system whereby the temperature difference between warm, surface water and colder, deeper water is used to power a heat engine. This mechanical power could be used either to produce electricity or subsequent energy-intensive products such as ammonia.

Oil shale: A solid mineral from which an oil precursor can be extracted.

Old gas and oil: Under federal price regulations, oil or gas from wells drilled before a certain date must be sold at a lower price.

Peak load: The electrical load above intermediate load that occurs from about 3 pm to 9 pm (varies regionally and seasonally). Typically constitutes about 5% of electricity generated.

Photovoltaic cell: A device that generates electricity directly from incident sunlight.

Power: Work done per unit time.

Price elasticity: The ration of the change in demand to a related change in price.

Pyrolysis: Controled heating of an organic substance in the absence of oxygen to produce gaseous or liquid fuels.

Quad: One quadrillion $(10)^{15}$ Btu.

RD&D Research, development, and demonstration.

REA: Rural Electrification Administration

Scenario: An account or synopsis of a possible course of action or events.

Solar thermal power system: A process for generating electricity by a heat engine that is driven by heat from concentrated sunlight.

SNG: Synthetic natural gas.

Stakeholders: A group of individuals who generally share a common point of view regarding specific decisions because they stand to gain or lose as a result of the decision.

TVA Tennessee Valley Authority.

Watt: A measure of power equal to one joule per second.

Work: The product of a force and the distance through which it acts.

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